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ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA

Incorporated 1880

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EVOLUTION OF THE STEEL SKELETON TYPE OF BUILDING*

By Robins Fleming†

THE BEGINNINGS

Introduction. The building code recommended by the National Board of Fire Underwriters defines the term skeleton construction as follows:

"A form of building construction wherein all external and internal loads and stresses are transmitted to the foundation by a rigidly connected framework of metal or reinforced concrete. The enclosing walls are supported by girders at each story."

The subject of reinforced concrete buildings will not be considered in this paper beyond mentioning that there are at present in the United States about 350 of these buildings, 10 stories or more in height, the record height being a 21-story office building in Dayton, Ohio, 274 feet, three inches from the sidewalk to the peak of the tower roof.

William Fairbairn (1789-1874) in his book, "On the Application of Cast and Wrought Iron to Building Purposes," 1854, states that the first instance on record of the successful application of cast-iron beams to the purposes of building is that of a fire-proof cotton mill built in Manchester (England) in 1801. The building was 42 feet wide between walls, 140 feet long, and seven stories high. The beams of an inverted T shape, the first of the kind made, were spaced nine feet apart longitudinally, with brick arches resting on the flanges. Two rows of cast-iron columns nine feet apart longitudinally and 14 feet transversely divided the building into three aisles. He also calls attention to the Saltaire mills, then nearing completion, the property of Titus Salt, afterwards Sir Titus Salt. This "magnificent establishment" was 50 feet wide, 550 feet long, and six stories high. "The whole of this building is fireproof, with stone walls, cast iron columns and hollow brick arches." The beams were cast-iron "of the section of greatest strength." The floor arches of hollow brick were a decided innovation.

*Presented at "Civil Engineering Conference," November 4, 1926. Received for publication January 12, 1927.

†Structural Engineer, American Bridge Co., New York.

In the third edition of this book, 1864, Fairbairn adds the description of a sugar refinery 58 feet wide, 150 feet long, and eight stories high. This building he says "is probably one of the most important yet constructed with arches in wrought iron beams." In a fourth edition, 1870, the author's name is given as Sir William Fairbairn, Bart. (Fairbairn declined a knighthood in 1861, but accepted a baronetcy in 1869.)

The "Encyclopædia Britannica,"* under "Steel Construction," says, "In 1881 the walls of a very large courtyard were constructed by building a braced cage of iron and filling the panels with masonry, a system of construction which had been used for a tall shot-tower located in the city of New York." The "large courtyard" probably refers to the New York Produce Exchange building, of which George B. Post was the architect. A diligent search through the early annals of New York has failed to locate a shot-tower answering to the description.

An iron-skeleton chocolate factory of three stories and a roof, resting on masonry piers in the River Marne, is described at length by Saulnier, its architect, in the "Encyclopédie d'Architecture" of 1874, vol. 3, page 116. A cut of this building, reproduced from the *Deutsche Bauzeitung* of July 10, 1878, may be found in the *Engineering News,* January 5, 1893, vol. 29, page 15. It does not seem that this structure aroused any suggestion of the possibilities of skeleton construction.

Cast-iron fronts were used so extensively in the United States during the '50's, '60's and early '70's that they mark a period. The first complete cast-iron front ever erected was put up in 1848 by James Bogardus, a civil and mechanical engineer, on the corner of Center Street and Duane Street, New York. It was five stories in height above ground, and covered an ordinary city lot, 25 by 100 feet. The building was removed in 1859, when Duane Street was widened.†

The largest and most noticeable of all cast-iron fronts was that of the A. T. Stewart (now John Wanamaker) store in New York, commenced in 1859, and rising 85 feet above the sidewalk. The store is five stories high and covers an entire block about 200 by 328 feet. The four fronts still face their respective streets in their pristine glory.

*Ed. 11.

† "A Review of the Development of Structural Iron," by William J. Freyer, in "A History of Real Estate, Building and Architecture in New York City," 1898.

The framework of the Crystal Palace, erected on what is now Bryant Park in New York, was a wonderful combination of cast-iron columns, cast-iron beams and wrought-iron, though of the 1800 tons of iron used in its construction, 1500 tons were cast-iron. The Palace was built to house the first World's Fair in the United States and was formally opened July 14, 1853. A writer of the time said that "it will long be remembered as the most tasteful ornament that ever graced the metropolis." The structure was not fire-proof. On October 5, 1858, in less than an hour, it was burned to the ground.

The foregoing illustrations may be regarded as approaches to the skeleton type of high building which we have to-day. Buildings had reached a limit of height before 1870. To build higher it was necessary that easy access be had to the upper stories. The passenger elevator was needed. In fact, for making the skeleton type of high building practicable we are mainly indebted to the following:

1. The rolled iron beam.
2. The passenger elevator.
3. Tile flat-arch floor construction.
4. The isolated footing.
5. The spread foundation.

These will be considered in the order named.

The Rolled Iron Beam. No epoch was greater or more far reaching in its effect on the extension and development of building construction than that of the rolling of iron beams. For this reason the subject will be dwelt upon at length. Fairbairn in the preface of the 1854 edition of his book, previously mentioned, has the significant sentence: "I conceive the most important section of the book will be that which is given to a recommendation of the advantages of wrought-iron beams or joists in substitution of the more cumbersome and uncertain ones of cast iron now in general use." He mentions no date when wrought-iron beams were first used. Evidently they were making their way slowly. An appendix to the book is written in their defense, concluding with the sentence, "I have deemed it necessary to give these facts in order to prove the superior efficiency of the wrought-iron beam; their comparative lightness, being only *one-third* of those composed of cast iron; and their greater security from frac-

ture, whether arising from a dead weight or the force of impact." It should be noted that the wrought-iron beams of Fairbairn are "manufactured"; that is, they are miniature plate-girders made of a web-plate and flange angles.

Beams of wrought-iron were first rolled in the United States at Trenton, N. J., in 1854. Peter Cooper, the principal owner of the Trenton Iron Works, in 1852, decided to begin the erection of the building in New York City so long known as Cooper Union. It was decided to use rolled beams not less than seven inches deep to support floors of brick segmental arches. Two years were spent at a cost of more than $150,000 in developing machinery that would roll such beams successfully. The first beams rolled were what is now known as deck beams and were used for the first floor of Cooper Union. The great printing establishment of Harper & Brothers, 82 Cliff Street, New York City, burned to the ground December 10, 1853. The loss of $1,500,000 was the largest fire loss sustained up to that time by a commercial house. The decision was soon made to rebuild at once a fire-proof structure with floors of brick arches resting on rolled iron beams. Mr. Cooper generously postponed the rolling of beams for his own building in order to roll those needed for the new building of Harper & Brothers. Immediately after the completion of the Harper building the United States government decided to make an extension to the Assay Office in New York City, using rolled iron beams for the floors. A further delay of the Cooper Union beams followed. On the completion of the Assay Office the government placed an order for 6000 tons of beams, which were rolled during the winter of 1855-1856 and the summer of 1856. The Cooper Union building was not completed until 1858. In 1854, Cooper & Hewitt, 17 Burling Slip, New York, advertised for sale wrought-iron beams for fire-proof buildings and announced that solid wrought-iron rolled beams would be cut to specified lengths at a price which would permit the erection of fire-proof buildings at a very moderate advance on the cost of wooden ones. They called the attention of the public to the new building of Harper & Brothers, where their beams had been used.*

Just here it may be stated that the Harper plant of six stories from the ground floor and two floors below street level was the first fire-proof building of any considerable magnitude. The cast-iron front

*"History of Architecture and Building Trades in Greater New York" 1899.

was imposing. The building covered more than half an acre of ground and many improvements, then but little known, were introduced in its equipment. The building was torn down in 1925 to give place to a three-story garage.

With the advent of the rolled iron beam the cast-iron beam was doomed. In a paper, "Historic Notes on Beams and Girders," by R. B. Woodworth, read before this Society and published in its PROCEEDINGS of February 1912,* the date 1870 is given as about the year of its disappearance as a unit in building construction. However, a paper, "Experiments on the Relative Strength of Cast-Iron Beams," presented April 16, 1886, may be found in the *Minutes of the Proceedings of the Institution of Civil Engineers.*†

The Phoenix Iron Company began rolling iron I-beams about 1860. This company's "Price Current," 1869, was the first of the procession of structural engineers' handbooks. It lists rolled iron beams from four inches, 10 pounds per foot, to 15 inches, 66 2/3 pounds per foot; also channels, angles and tees. The distinctive feature is the "Phoenix" column. The patent for this column bears the date of June 17, 1862. These columns at once met with a favorable reception. The second of our handbooks, that of the New Jersey Steel & Iron Company, 1871, lists rolled I-beams from four inches, 10 pounds, to 15 inches, 66 2/3 pounds.

According to the "Inside History of the Carnegie Steel Company," by J. H. Bridge,‡ the first iron beams made in Pittsburgh were rolled on a 20-inch mill set up by Andrew Kloman in 1865. The first edition of the "Pocket Companion" of Carnegie, Kloman & Company (proprietors of the Union Mills), dated 1872, lists iron beams from four inches, nine pounds per foot, to 15 inches, 67 pounds per foot. Channels, deck beams, tees and angles are listed; also patent wrought-iron columns of octagonal shape.

The rolling of steel beams marked another epoch in building construction. They were listed for the first time in the "Pocket Companion" of Carnegie, Phipps & Company, dated 1884. The "Companion," 1892, was the last one to list both iron and steel beams. The preface to the edition of 1893 states, "Our product hereafter will

*V. 28, p. 11-81.
†V. 86, p. 235-252.
‡Aldine Book Co., New York. 1903.

be exclusively steel." The age of steel had begun. A paper, "Steel in Construction," by Albert F. Hill, read before this Society April 20, 1880,* confidently states that "Steel construction is undoubtedly *the* construction of the near future."

A notable handbook was "Structural Steel," issued by the Bethlehem Steel Company in 1907. Wide-flange "special" and "girder" I-beams are listed from an eight-inch I, 16.25 pounds per foot, with flange 5.19 inches wide, to a 30-inch I, 200 pounds per foot, with flange 15 inches wide. Rolled steel columns of H section are listed from an eight-inch, 27.7 pounds per foot, to a 14-inch, 291.2 pounds per foot. These sections were made possible by the Grey universal beam mill. Instead of the horizontal grooved rolls of the ordinary beam mill, the Grey mill has horizontal and vertical rolls, by which the flanges of an I-beam shape are each produced by combined rolling operations acting at right angles. Wide-flange beams had been rolled in Germany several years before being introduced in the United States by the Bethlehem Steel Company.

Professor E. S. Andrews, in the *Structural Engineer,* London, May 1926, says,

> "Henry Grey, of St. Louis, U.S.A., developed the process of rolling I-beams by means of the universal mill. In his first British patent of 1896 he describes a process and mill for rolling I-beams, the principal feature being that the vertical rolls of the first pass are driven from the horizontal rolls through friction gearing which ensures a positive rolling action in two planes while providing a flexibility in the drive. He provided a second pass, the rolls of which rolled the edges of the flanges; this second pass is arranged close to the first so that the section is under the action of both sets of rolls at a time."

The Passenger Elevator. The epoch in building construction next in importance to that of the rolled beam is that which marked the introduction of the passenger elevator. High buildings were thus made practicable—that is, buildings of seven, eight, and nine stories, to say nothing of those of 20, 30, and 40 stories. "It was the elevator that taught men to build higher and higher." "The elevator has figuratively turned the atmosphere into gold." The evolution of the elevator is a story in itself. The hand-power elevator was patented

*Proceedings, v. 1, p. 106-120.

in 1846. A vertical-screw elevator was placed in the Fifth Avenue hotel, New York, about 1856. The first suspended steam elevator of the Otis type was installed in the St. James hotel, New York, in 1866. The Equitable Life Assurance Company of New York was the first corporation to put up a great office building in connection with its own business. The work was carried on slowly and extended over several years. An elevator was installed in the first section built in 1868, and others in later sections. The building was destroyed by fire January 9, 1912. In the present Equitable building are 48 elevators for general and 20 for special uses. Of the 30 elevators in the Woolworth building, two rise from the first to the fifty-fourth floor, a vertical distance of 700 feet, 2½ inches, in one minute. In 1873 a water-balance elevator was placed in the Western Union building and continued in service until destroyed by a fire in 1891. In 1878 the vertical cylinder hydraulic type of elevator was introduced in New York City. It was but a few years until the hydraulic elevator had almost a monopoly of the field. An electric elevator was installed in a building in Baltimore in 1887, but it attracted little attention; yet in less than five years the electric elevator was competing with the hydraulic for speed in passenger service.

Major W. L. B. Jenney, of whom more will be said later, in an early article, "Strength of Buildings" (*Engineering News*, May 26, 1877, vol. 4, page 139, reprinted from the *Chicago Tribune*), calling attention to the danger of overloading the floors of commercial buildings, says,

> "This is now the more likely to occur on account of the general use of steam or water elevators, which render all parts of a building equally accessible and the upper stories formerly used only for the lightest material are now often stored with the heaviest goods, for in the busy season all our wholesale houses are liable to be short of room, and goods once on the elevator are taken to any story where there may be room for them."

Tile Flat-Arch Floor Construction. As buildings grew in height it became necessary to reduce the dead load of the floor construction. Brick arches leveled with concrete were heavy. Besides, the lower flanges of the beams upon which they rested were not protected from fire. The question of providing better fire protection for beams, girders, and columns demanded attention. Steel begins to lose its

strength at 600 degrees F., and at 1000 degrees has little value in supporting loads. As it does not require a great fire to produce a temperature of 1000 degrees the importance of fireproofing is readily seen.

Hollow tile as a building material was introduced in the United States in 1871, shortly after the Chicago fire. William J. Freyer, in the book previously quoted, writes:

> "An American citizen, Balthaser Kreischer, a well-known manufacturer of firebrick in New York City, invented and patented in 1871 the use of hollow tile *flat* arches between iron floor beams. . . . It was in the U. S. Post Office in New York in 1872-3 that for the first time in this or any other country were introduced hollow or flat tile arches between iron floor beams. In the same year 1872, the Kreischer floor arches were placed in the Kendall Building, Chicago."

The Kreischer patent after long litigation was declared void. The "end-construction" arch took the place of the "side-construction" arch in the early '90's. At present the reinforced concrete slab is in great favor.

As with the passenger elevator, the story of floor and roof construction, together with fireproofing, is a story in itself. Many systems have been devised. The section, "Fireproofing of Buildings," by Rudolph P. Miller (then Superintendent of Buildings, New York City), in edition 17 of the "Architects' and Builders' Handbook,"* by F. E. Kidder and Thomas Nolan, is a concise presentation of the subject.

The engineer understands that the term fire-proof is a misnomer. No building is absolutely fire-proof. The National Fire Protection Association recommends the discontinuance of the term and the use of "fire resistive" instead.

The Isolated Footing. It was long the practice to make the foundation of heavy and important buildings one continuous bed of concrete or solid masonry. In the churches of Europe this bed was often exceedingly thick, and this thickness was relied upon to resist the uneven reaction from the pier and wall loads. In the government post-office and custom house in Chicago, built in 1877, the foun-

*John Wiley & Sons, New York. 1921.

dation bed was of concrete three feet, six inches thick. The building settled so badly and so unevenly (24 inches in places) that after but 18 years' service it had to be replaced by a new one.

The method of each column and wall in a building resting on its own foundation, independent of all others, was first advocated by Frederick Baumann, a Chicago architect. His pamphlet, "The Method of Constructing Foundations on Isolated Piers," published in 1872, introduced a new principle in foundation construction. On compressible soils all foundations will settle some. The object of the isolated footing is to have the area of the foundation bed so proportioned that settlement will be uniform. With the live load not constant and a different ratio of live to dead load on different columns, a problem presented itself at the very outset of high building construction. The character of the soil will determine the allowable pressure per unit of area. Many methods of apportioning the live and dead loads have been suggested. Building codes of different cities have requirements of their own—not always in accord with good engineering.

The Spread Foundation. In present-day high building construction the steel or reinforced concrete footing is closely allied to the isolated pier. In fact, it is the isolated pier carried into practice. J. K. Freitag, in his "Architectural Engineering,"* writes,

"In the Montauk Block, ten stories, built in Chicago in 1881-2 by Burnham & Root, Architects, the foundation piers were made of layers of concrete 18 in. thick, on top of which were placed dimension stones forming pyramids, thus nearly filling the entire basement. Under two stacks of fireproof vaults, such foundations would have interfered with basement space where it was desired to locate boilers and engines, so that, under these conditions, the innovation was adopted of embedding iron rails in the concrete footings to increase the allowable offsets in the concrete layers. This constituted a most important precedent, which has gradually developed into present grillage design."

Soon I-beams were used in the upper course in place of rails, then altogether. To quote Freitag once more,

"It was not until the same architects (Burnham & Root) designed the Rookery Building in 1885-6, that isolated footings were really employed with

*John Wiley & Sons, New York. Ed. 2, 1901.

the use of steel members. In this building the footings were made of two courses of steel laid at right angles to each other and embedded in concrete, with I-beams crossing the upper courses, on which were placed cast column bases. The masonry walls were self-supporting."

Baumann, in his pamphlet previously mentioned, lays down as one of the fundamental rules in designing foundations that they must be made to support their loads centrally. That is, the center of gravity of pressure should coincide with the center of gravity of resistance. To do this is sometimes an interesting and difficult problem. Two or three unequally loaded columns may be required to be carried on the same footing. Columns against party lines where footings can not be extended over adjoining property must be carried on cantilever girders. The corner column if adjoining two party lines is not always easy of solution. Allusion is made to an "Analysis of the Continuous Three Column Foundation," by Professor C. A. Ellis, in the *Engineering News-Record*, October 7, 1920, vol. 85, page 680.

THE SKY-SCRAPER

The great Murray "Dictionary of the English Language on Historical Principles" gives as one of several definitions of the word, sky-scraper, "a high building of many stories, especially one of those characteristic of American cities," and cites the *Boston Journal*, November 1891, as using the word for the first time. Evidently the word as applied to a building was in use before that date. James Maitland's "American Slang Dictionary," published in 1891, defines sky-scraper as "a very tall building such as now are being built in Chicago."

The question as to who was the originator of the sky-scraper comes up periodically. Now, if by a sky-scraper is meant a building of many stories designed so that all loads are carried and all forces resisted by an iron or steel frame, the sky-scraper as we have it to-day is not wholly the invention of any one man. It is an evolution. The names of Jenney, Burnham, Holabird, Roche, Purdy, and Sullivan, all of Chicago, are inseparably connected with early construction of high buildings.

To Major W. L. B. Jenney is usually (and rightly) given the credit of being "the real father of the modern tall building—or

rather the form of skeleton construction that made it possible." William Le Baron Jenney (1832-1897) served as an officer of engineers under Grant and Sherman in the Civil War. In 1868 he settled in Chicago as an architect, for which profession he was pre-eminently fitted by his previous studies. In the fall of 1883 he was appointed architect for the Home Insurance Company of New York and commissioned to prepare designs for an office building in Chicago. The 10-story Home Insurance building designed by him and finished in 1885 was an original and marked departure from previous practice. The floors of the building were carried entirely by cast-iron columns and wrought-iron beams (A few steel beams were used experimentally—the first use of steel beams in a building). The exterior columns, however, carried only that portion of the wall load that came upon them from the cast-iron box lintels over the windows. Major Jenney makes this building the subject of an article, "The Construction of a Heavy Fireproof Building on Compressible Soil," published in the *Sanitary Engineer*, December 10, 1885, vol. 13, page 32. Major Jenney states that

> "The system of foundations adopted was that of independent piers, each basement pier and each interior column having its independent foundation. To the weight of the building there was added a further weight of 18 lbs. per sq. ft. for the average permanent load on the floors. The inequality of settlement was less than three-fourths of an inch. Iron was used as the skeleton of the entire building except the party walls. The girders carrying the I-beams of the floors rested on brackets on the iron columns. A square iron column was built into each of the piers in the street fronts. All columns and mullions were continuous from the bottom plate to the top of the building."

The Home Insurance building was not an example of a complete skeleton structure. Advances and improvements were made later by others, but it was Major Jenney who inaugurated a new era in building construction.

The 12-story Rookery building, 1886, "one great pile of marble, and iron, and glass, and tiling," had isolated footings, rolled beams, and cast-iron columns.

In the 14-story Tacoma building, finished in 1887 (Holabird & Roche, architects), the two street frontages were curtain walls carried at each floor by cast-iron spandrel beams to cast-iron columns.

On the other two sides were masonry walls. Although not a complete metal frame, it introduced successfully skeleton wall construction, and this type came into use very rapidly thereafter. (See "Growth of Steel Frame Buildings," by H. J. Burt, *Engineering News-Record*, April 17, 1924, vol. 92, page 680).

The three original sky-scrapers, the Home Insurance, the Rookery, and the Tacoma, are at present apparently as good as they ever were and are well filled with tenants.

The Rand-McNally building, designed by Burnham & Root in 1889, was the first large building in which steel columns were employed throughout. The Leiter building, designed soon after by Jenney, was the first building in which there was not even one self-supporting wall. The Fair building, built in 1891, also designed by Jenney, had Z-bar columns, one section of which had an area of 142 square inches, the largest section of column at that time in Chicago. The Z-bar column had recently been introduced in the United States by C. L. Strobel (See his article, "Experiments Upon Z-Iron Columns," *Transactions of the American Society of Civil Engineers*, April 1888, vol. 18, page 103). Mention might here be made of the Auditorium building, commenced in 1887 and completed in 1890. "There is certainly no other structure in America that equals the Auditorium," says a Chicago guide-book of 1892. "The magnificent banquet hall is built of steel in trusses spanning 120 feet over the Auditorium."

The Masonic Temple (Burnham & Root, architects), a 20-story building, was erected in 1890. The building extended 170 feet on State Street to a 40-foot alley, and 113 feet on Randolph Street to a 25-foot alley, and reached a height of 272 feet, 10 inches from grade to top of coping. Though not the highest tower, it was the highest building in the world. Spread footings with four courses of steel rails were used for foundations. Box columns in two-story lengths, made of plates and angles, were used, lattice-bars taking the place of plates where loads were light. To give greater rigidity to the structure only alternate columns were spliced at the same floor. The building was a bold piece of work and illustrated the possibilities of steel skeleton construction. The structural work was designed by E. C. Shankland, later of the firm of E. C. & R. M. Shankland. Incidentally, this firm designed the steelwork of several of the early high

buildings of Chicago. To the credit of E. C. Shankland is the structural design of many of the buildings of the Columbian Exposition of 1893—notably the 328-foot arch trusses of the Manufacturers' building.

By this time a phenomenal demand had set in for high buildings not only in Chicago, but in other large cities. This was not strange. Offices in the new buildings were light, airy, and sanitary, and equipped with conveniences unknown to those of the older type. Business prestige and better service were obtained. The buildings were less noisy. Partitions could be removed or altered and floors divided to suit tenants. Perhaps the greatest advantage was in the matter of light. Steel columns and thin curtain walls carried by steel beams took the place of heavy brick masonry. If the carrying capacity of a steel column is 12,000 pounds per square inch, and a pier of good brick laid in cement mortar is 200 pounds per square inch, the great reduction in sectional area that can be effected is readily seen. "Light is most essential. It is a good rule to leave out of doors all the space that can not be satisfactorily lighted. The small size of the piers, nearly the same dimension in the lower stories as in the upper, is one of the most important advantages in steel skeleton buildings." (See "Steel Building Construction," by Jenney, *Engineering Record*, January 6, 1894, vol. 29, page 90.)

The engineering papers of the '90's have many valuable articles by C. T. Purdy relating to high buildings. In a paper read before the Boston Society of Civil Engineers,* entitled "The Use of Steel in Large Buildings," he says:

> "This reversal of building methods, this change about in the function and use of masonry walls, and the introduction of such new conditions in large buildings is a real revolution, the extent of which can hardly be realized. The result is that the constructive side of the problem has reached its most perfect development in Chicago practice. The rapidity and history of its development can be very readily traced in that city. A new idea is tried to a limited extent in one building, a bolder application of it is attempted in the next; another idea, originating in another office, is worked out in the same way. Thus the evolution proceeds and honors are extremely hard to divide."

*Journal of the Association of Engineering Societies, 1895, v. 14, p. 182.

In leaving Chicago attention is called to the 34-story Tribune Tower building. Probably nowhere else can be seen so strikingly the evolution through which steel skeleton construction has passed. It is a long way from the demands put upon the designer of the structural steelwork of the early box-shaped rectangular buildings to the severe conditions met by the engineer who designed the steelwork to conform to the esthetic conception of the architect of this building.

SKELETON CONSTRUCTION IN NEW YORK CITY

An impetus was given to iron and steel construction in New York City by the Building Department passing in 1882 a regulation requiring all buildings more than 85 feet high to be fire-proof. Great strides were made in iron construction in the design and building of the Metropolitan Opera House, formally opened October 22, 1883. Writing of this building Louis de Coppet Berg says, in 1892, in the *Architectural Record*, vol. 1, page 459:

> "The span of the roofs and ceilings in this Opera House, considerably over 100 feet, gave an opportunity to show what could be done in light iron truss construction. This building, too, was one of the earliest buildings into which the use of riveted girders of modern design entered. The span of these riveted girders was so great, that their weight was beyond anything that had been hoisted before them, and after they had broken down a successive series of derricks, special derricks had to be devised to get them into place."

These trusses and girders were pygmies compared with some that have since been erected. The first of the roof trusses of the Paramount Theater building was put in place February 23, 1926. The traveler used was 52 by 72 feet, and 84 feet high. On its top were two derricks with 50-foot masts and 75-foot booms. The main trusses to be lifted were 122 feet long, and 16 feet high, and the steel in each weighed 146 tons. About five tons of appurtenances had to be lifted with each truss. The vertical distance from the pit where they were assembled to where they span the auditorium is 130 feet. (See *Engineering News-Record*, March 18, 1926, vol. 96, page 451.)

Another interesting feature about the Metropolitan Opera House is that it was the first example of fire-resisting construction

throughout. Berg, in the article previously mentioned, pronounced it "the first absolutely fire-proof theater in the world"; yet, on Aug. 27, 1892, only a few weeks after the publication of his article, the interior was destroyed by fire. On November 28, 1893, the building was re-opened with the interior entirely remodeled.

Though the type of building we now know as the sky-scraper originated and reached large proportions in Chicago, it has arrived at its greatest development in New York City. Coming into the harbor by steamer or to the city by river on the ferry-boat, the sky-line serrated by many high buildings presents a most imposing sight. No other city in the world can equal it.

The first building of skeleton construction in New York City was the Tower building (Bradford L. Gilbert, architect), erected in 1888-1889 and demolished in 1914. The structure of 10 stories, basement and cellar was 21½ feet front, 39½ feet rear, and about 108 feet deep in the narrow portion. From the sidewalk to the main roof was 129 feet. The walls and floors were carried entirely by the iron framework. Considerable difficulty was encountered in obtaining the approval of plans by the Building Department, as doubts existed regarding the safety of the proposed structure. A tablet was placed on the building by the Architectural Iron Manufacturers of New York City, calling it the "earliest example" of skeleton construction. This claim has been vigorously denied. It seems to the writer that Gilbert is entitled to recognition as taking an advance step in the evolutionary process of skeleton construction rather than being its originator. Within 30 years from the completion of the Tower building there were in New York City more than 1200 fire-proof buildings of 10 stories or more in height. The "Eagle Almanac" for 1926 lists 58 buildings under "Notable New York Buildings," every one of which is more than 250 feet high.

The World building, noted for its dome, was erected in 1889-1890. The floors and roof are carried by rolled beams and "Phoenix" columns. The outer columns stand clear from the walls, and the walls are of solid brick and of great thickness, although supporting nothing but their own weight.

According to Freyer, the second building of skeleton construction type in New York City was the 10-story Lancashire Insurance Company building, finished in May 1890, and the third was the 12-story

Columbia building, 1890-1891. Columns of Z-bars were used in the Lancashire building. The first building of note was the Manhattan Life building, built in 1893, 67 by 120 feet, and 17 stories high, with a tower on top terminating in a dome. The main roof is at an elevation of 242 feet from the sidewalk, and from the sidewalk to the base of the flag staff is 347 feet. The building was at the time the highest in New York City, "60 feet higher than Trinity Church." A unique feature in the construction of this building was the employment, for the first time in building work, of pneumatic caissons sunk by means of compressed air.

A digression may here be permitted. Trinity Church, almost opposite the Manhattan Life building, when it was finished in 1846 became at once one of the sights of New York. Francis's "New Guide to the Cities of New York and Brooklyn," dated 1853, in the section on Trinity Church mentions "its immense height, towering as it does 284 feet into the air," and concludes with:

"The highest point to which visitors ascend is 250 ft. from the ground, and is reached by 308 steps. Suitable resting places are provided, so that the ascent is not difficult. As is very proper, a charge of one shilling is made for admission to the spire. The body of the church, at any time when there is no service, may be seen without charge."

A later guide book, "New York and Its Environs," 1891, says, "The steeple and spire of Trinity church are 284 feet high. The ascent of this steeple was formerly one of the usual incidents of a visit to New York, but strangers are no longer admitted unless they obtain a permit from the rector." The churchyard is now flanked on each of its four sides by buildings of 20 or more stories in height.

In 1896 came the 26-story St. Paul building, followed in 1898 by the 30-story Park Row building. This building at the time was the highest office building in the world, and it was thought that the limit of height had been reached. It was so thought when the Masonic Temple of Chicago was finished.

In 1907 there were four record-breaking buildings in process of construction at the same time—the Terminal building (See *Engineering News*, January 3, 1907, vol. 57, page 14), the Metropolitan Tower (See *Engineering News*, January 31, 1907, vol. 57, page 38), and the Singer and the City Investing (now the Benenson) building (See

Engineering News, December 5, 1907, vol. 58, page 595). The Hudson Terminal is really two buildings, one on each side of Dey Street, connected by bridges and sub-basements. The buildings are 22 stories high and the combined buildings broke the record in having, when finished, more than double the office space of any other building in New York. The 41-story Singer building, with a four-story lantern on top of the tower, rising to a total height of 612 feet above the sidewalk, made it the highest office building in the world. The 48-story tower of the Metropolitan Life building, finished later, rose to a height of 658 feet, making it the highest office building in the world. The City Investing (now the Benenson) building of 25 stories held the record for carrying the major portion of the area to the greatest height.

In 1913 two record-breaking buildings were in process of construction, the Woolworth and the Equitable (See *Engineering News*, July 30, 1914, vol. 72, p. 225, 232), the records of which for height and size have not been broken. The Woolworth building, formally opened April 24, 1913, is probably the best known office building in the world. The main portion is 30 stories high, and the tower portion, about 85 feet square, has offices in the fifty-third story. The observation gallery is 58 stories above the street. The base of the flagpole is 760 feet, six inches above the curb, and the highest point of the building is 792 feet, one inch above the sidewalk. The maximum column section is 700 square inches, and the steel framework weighs 24,000 tons.

It may be said that the tower building is at present the favorite form of the skyscraper. "It is the one architectural style assumed to be suited equally well to church, business building and governmental structure." While the Singer, the Metropolitan Life, and the Woolworth buildings are of the tower type, the 36-story Equitable building has a distinction of its own. The ground plan area is carried up undiminished to the top. The building covers an entire block of an average width of 159 feet, and average length of 308 feet, and rises to a height of 542 feet from the Broadway sidewalk to the coping. The floor space is slightly more than 1,200,000 square feet. The framework required 32,000 tons of steel.

The "Building Zone Resolution" of New York City was adopted July 25, 1916. For the purpose of limiting the height and bulk of buildings the city is divided into six classes of districts. The permis-

sible height in each class is dependent upon the width of the adjoining street, with the provision that for each one foot that the building or a portion of it sets back from the street line a certain number of feet shall be added to the height limit. The building must also set back from the rear line of the lot. The permissible heights vary according to the district to which the building belongs. "No more Woolworth buildings in New York" was the thought of many on reading the Resolution. While this is a probability, it is not an assured fact. According to William E. Walsh, Chairman of the Board of Standards and Appeals, "Zoning regulation is now celebrating its tenth anniversary in New York City and seems to have worked out more successfully here than in many other places where it has been tried, and so it might reasonably be considered an efficient zoning system."

The Ley building, a 20-story store and office building, finished in 1919, was the first high building to illustrate to any extent the working out of the set-back requirements of the Building Zone Resolution. Notable buildings of more recent date are those illustrated in an article, "Treatment of the Set-Back," by DeWitt Clinton Pond, in *Architecture*, October 1926.* Professor Pond writes:

> "Although the main parts of the building must come within the limits established by the sloping lines, in order to grant the architect a certain freedom to accomplish artistic ends, certain exceptions are allowed by the law. Dormers may be built out; and towers, the areas of which can not exceed 25 per cent. of the lot, may be carried to any height. By taking advantage of such exceptions, architects are able to mold the upper part of their buildings with the various shapes that are becoming characteristic of the newer skyline of New York."

A New York architect writes, "Limiting the height of buildings was written into our zoning law to meet two demands—more sunshine, less congestion. In obtaining more sunshine the law was a success; in bringing about less congestion it was a total failure."

Buildings in Other Cities. Chicago and New York did not long remain alone in the matter of skeleton construction. The craze for high buildings spread with startling rapidity to other cities. It became a matter of civic pride for even small cities to have at least one sky-scraper—"one that can be illustrated on a picture postcard and

*V. 54, p. 293.

sent far and wide as an evidence of modernity and a go-ahead spirit." In Miami, Fla., at the beginning of 1926, there were more than a dozen steel and concrete frames rising from 14 to 20 stories above the street. While New York leads in high buildings and buildings with unusual features, it does not have an exclusive field. The L. C. Smith building of Seattle is 42 stories high, 21 stories in the main building and 21 in the tower. When it was finished it had the distinction of being the highest building in the world outside of New York City. The Union Trust building in Cleveland and the General Motors building in Detroit have each more than 1,000,000 square feet of floor space. Cleveland's new Union Station is to rise some 700 feet above the ground. The Wanamaker stores in Philadelphia required 28,000 tons of steel in their construction. The recently completed 26-story Telephone building of San Francisco, 150 by 160 feet, rising 436 feet, has other claims on our attention besides its colossal dimensions.

In each of our larger cities is enough material to warrant a paper on the development of steel skeleton construction in that particular city. This is especially true of Pittsburgh. The present writer will leave such a paper to be prepared by a member of this Society or by some one who has ready access to the facts.

The "Cathedral of Learning" for the University of Pittsburgh was originally planned as a 52-story building.

The Cast-Iron Column. The strong hold maintained by the cast-iron column after steel came into use seems strange to the structural engineer of to-day. The early buildings of Chicago had cast-iron columns, the 17-story Unity building being one of them. Able engineers pointed out objections to their use—they are not continuous and connections to them have to be made by bolts, causing a lack of the stiffness desirable to resist wind forces. Again, cast-iron is not homogenous, is subject to internal stresses in cooling, and has little elasticity. A cast-iron column, owing to the shifting of the core, might have a shell very uneven in thickness, but impossible of detection by ordinary inspection. The advocates of cast-iron columns emphasized their superiority to steel as regards resistance to fire and rust. More potent arguments in their favor were that they could be furnished more cheaply and in shorter time than steel columns. The

foundry interests were strong and did not care to lose their market. However, one after another the advocates of cast-iron fell into line in favor of wrought-iron and steel for columns. Steel had largely taken the place of cast-iron when the Darlington Apartment House, a 13-story building in New York City, collapsed, March 10, 1904, during erection. Square cast-iron columns had been used throughout, and to lack of lateral support for these columns was attributed the main cause of the disaster. This disaster acted as a deterrent to the further use of cast-iron columns in high buildings.

Wind Bracing. At the very beginning of high building construction a problem that presented itself was that of wind bracing. There is still a great divergence of opinion on the subject among engineers. The building codes of our municipalities, in accordance with which most high buildings are presumably designed, are at wide variance in their requirements.

The first question to be decided is the pressure to be assumed per square foot of exposed surface. Note the evolution in our textbooks. A. J. DuBois in the first edition of his book, "The Stresses in Framed Structures," 1883, in calculating the stresses in a roof truss, takes "the greatest pressure of wind to be anticipated" at 50 pounds per square foot against a surface perpendicular to its direction. He assumes the wind to be horizontal. Mansfield Merriman and H. S. Jacoby in the first edition of their "Text-Book on Roofs and Bridges," 1888, assume the wind under the same conditions to be 40 pounds per square foot. Johnson, Bryan, and Turneaure in the first edition of "Modern Framed Structures," 1893, place the value at 30 pounds per square foot. The present Chicago code calls for 20 pounds per square foot; the New York code, 30 pounds; the Boston code, 10 pounds for the first 40 feet of height, 15 pounds from 40 to 80 feet, and 20 pounds for the part of the structure over 80 feet in height. The Pittsburgh code calls for 15 pounds.

Interesting discussions follow two early papers: "Wind Bracing in High Buildings," by Henry H. Quimby,* and "Wind Bracing in High Buildings," by Guy B. Waite.† Every structural engineer can profitably read the paper on "The Structural Design of Buildings,"

*Trans. A. S. C. E., 1892, v. 27, p. 221.
†Trans. A. S. C. E., 1895, v. 33, p. 190.

by C. C. Schneider (*Transactions of the American Society of Civil Engineers*, June 1905, vol. 54, pt. 7, page 371), and the extended discussion it brought forth.

The second question to be decided in the matter of wind bracing is the method of framing that shall be adopted to resist the assumed wind pressure. Here again an evolution has taken place. One of four methods was commonly used in the early high buildings. The simplest and least expensive was that of sway rods. With connections properly made there was little, if any, bending moment in either column or lateral strut. Another method was that of lattice girders, still another that of knee braces, and a fourth that of providing a system of web-plate portals placed one above the other. The 14-story Reliance building of Chicago, built in 1894 on a lot 55 by 85 feet, was braced by 24-inch plate-girders at each floor between the outside columns, "thus binding the columns together and transferring the wind strains from story to story on the table-leg principle." (The Reliance building was the pioneer in the use of terra-cotta for the exterior.) These systems were all effective—perhaps equally so. They all interfered sadly with rooms, corridors, doors and windows. Except in special cases and for buildings considered unusual, they have all given way to the gusset-plate type of connections. A crude approach to this type was used in the 13-story Fort Dearborn building (1894-1895), in Chicago (Jenney & Mundie, architects). Major Jenney in a paper, "The Wind Pressure in Tall Buildings of Skeleton Construction,"* in 1894, says, "the idea . . . was, we think, first suggested in general terms by the late Wm. H. Scherzer, an engineer of the Carnegie Steel Co. and Keystone Bridge Co., which we worked out in detail." Wind-bracing connections have taken many forms. Attention is here called to the method used by S. C. Weiskopf (at one time a member of this Society) in the 20-story Trinity building (1903), in New York City. In this system the regular floor girders are pairs of channels, beams, or plate-girders straddling the columns, and either the girders or splice plates at the ends are riveted to the side faces of the columns. The connection is developed within the depth of the girder.

*Proceedings of the American Institute of Architects, v. 28, p. 153.

Heights of Buildings. A matter of vital interest, affecting the development of the sky-scraper to a marked degree, is that of the zoning laws now in effect in so many cities. As buildings increased in height, it was found that they were not unmixed blessings, for they encroached upon the rights of the public and often worked injury to their neighbors. Chicago was the first city to pass an ordinance limiting the height of buildings within its bounds. By an ordinance passed in 1892, vetoed by the mayor, passed in 1893 and changed several times since, the limiting height has fluctuated from 130 to 260 feet; at present it is 264 feet on the building line plus additional height with set-back. The United States Department of Commerce, under date of April 1, 1926, states that grouped according to population 47 of the largest 68 cities having over 100,000, and 150 of the 287 cities and towns having over 25,000 population, had zoning ordinances in effect. In some cities (as in Detroit) it is stipulated that "Fireproof construction buildings shall not be limited in height." As these lines are being written there comes the announcement that work has been commenced in Detroit on what is to be "the world's tallest building." The Book Tower, as it is to be called, will be 873 feet high, as compared with the 792 feet of the Woolworth building, and will have 81 stories—23 more than the Woolworth.

The Battles of the Sky-Scraper. The sky-scraper has always been a matter of controversy—from architectural, legal, and economic standpoints. As Purdy said more than 30 years ago, "The change to steel construction is forced. The classical student has no liking for it. Commercial interests tend to overbalance all other considerations, East as well as West." The files of the architectural papers of those early days are interesting reading, and the following instance is typical of many. After the Tacoma building was erected, the writer of a staff article in the *American Architect* of June 22, 1889, vol. 25, page 294, quoting the phrase "commercial architecture" says:

> "This is really the keynote to all of these huge buildings already built or about to be built. They are specimens of 'commercial architecture,' and as such they are unquestionably a success; but, when viewed in any other way, it takes the most deceiving drawing from impossible points of sight, and with impossible sunlight and shadows, to make them even approach within hailing distance of the artistic."

The legal battles of the sky-scraper can not be taken up in this paper. The economic phases are many and complex. It has been written more than once that the sky-scraper had reached its "zenith." An article, "Limitations to the Production of Skyscrapers" in the *Atlantic Monthly*, October 1902,* closes with, "the mania for mere bigness is bound to give place to a better conception of corporate eminence." George C. Nimmons in an article, "The Passing of the Skyscraper," in the *Journal of the American Institute of Architects*, November 1922,† concludes that in Chicago, from an economic view, the sky-scraper becomes less profitable as it becomes more than 15 stories in height. Studies made elsewhere by others have given far different results. Many factors enter into the economic height and it varies widely. The sky-scraper is not passing, at least in New York City. The *New York Times* for June 12, 1926 (the same day that the writer made notes from the foregoing article), notes projects for one 39-story building, and for the "New Park Avenue Hotel" and the "Salmon Tower," to be 30 stories each. The issue of 11 days later announces that a firm of New York brokers had underwritten an issue of bonds for a 41-story building in the financial district of Chicago to be known as the Bankers' building.

Within half a dozen blocks to the south from the office in the Terminal building where these lines are being written is a sign—"A 35-story Office and Banking Building will be erected on this site. Ready for Occupancy about April 1, 1927." And about the same distance to the north is a sign—"42-story office building being erected." The *Bulletin* of the City Club of New York for October 1926 under "More Skyscrapers Coming" states that from January 1 to September 1, 1926, plans for 70 non-residential buildings, each of more than 12 stories, have been filed in the Bureau of Buildings of the Borough of Manhattan. This number consists of 29 hotels, 23 office buildings, and 18 factory buildings. It does not include a single tenement or apartment house.

The Future of the Sky-Scraper. Again and again the sky-scraper has been pronounced a peril. In brief, the arraignment against the high building is that it disturbs land values; it shuts out sunlight from

*V. 2, p. 486.
†V. 10, p. 356.

the street and from opposite buildings; it puts the city to heavy expense in providing fire protection, water-supply and sewerage; it adds seriously to the traffic problems. "Concentration spells congestion." Take the Equitable building as an illustration. More than 10,000 persons arrive in the morning and leave in the evening. This number is sufficient to monopolize the capacity of the nearest subway station for 45 minutes. The automobile traffic, so terribly increased the past four years, adds to the congestion. Streets are at times almost impassable. What the present congestion in a city means, or may become in the future, is graphically shown in a number of photographs from "aerial surveys" in an article, "Skyscrapers," by Frederic A. Delano, President of the American Civic Association, in the *American City Magazine* of January 1926, vol. 34, page 1. The titles under the illustrations are thought provoking, so much so that they will be quoted even if the pictures can not be reproduced. They are:

Sky-scraper congestion at the tip of Manhattan Island, New York City.

Similar conditions developing in down-town Pittsburgh.

Detroit's sky-scraper district creates serious traffic congestion in the automobile city.

Baltimore also is piling up trouble as big buildings multiply in a small central area.

Tall buildings without adequate setting are characteristic of San Francisco as of other great American cities.

When Dallas' 200,000 becomes a million, will this condition be five times worse?

Will Chicago maintain the fine standards set by the Wrigley Building and Tribune Tower in the new sky-scraper district now developing outside of the "Loop"?

"The sky-scraper must go" is the pronouncement of Henry H. Curran, a well-known member of the New York Mayor's Committee on City Planning. He would limit the height of buildings to six stories on a side street and 10 stories on an avenue. He would abolish all set-back privileges by which sky-scrapers are permitted to ascend in steps. While such a radical step, not at all likely to be taken, would relieve congestion, it would not abolish it. If for an extended area everybody along an avenue built to a height of 10 stories and everybody along the side streets to a height of six stories, the city would be uninhabitable. Such a result is not to be antici-

pated, but it shows that an ideal regulation for sky-scrapers must include limits for area as well as for height.

Conclusion. No adequate history of the development of iron and steel building construction has yet been written. This paper is but a mere outline of what should be done. We have a great mass of material, but it is fragmentary and scattered through innumerable articles and papers. Such a history should be written under the auspices of one of our engineering societies. It can hardly be entirely the work of one man, although it will be necessary to have an editor-in-chief. Access should be had to the files of building departments, and printed data verified. Co-operation and collaboration will be needed. A difficulty will be to find a publisher, unless the costs of bringing out the book are assumed by the engineering society in charge of compiling the work. It is needless to say that the history should be written while many who are cognizant of the wonderful growth and development of the past 50 years are still living.

DISCUSSION

J. A. McEwen:* The discussion of steel skeleton buildings by Mr. Fleming is both interesting and instructive. We wish to sidestep just a little and add a few remarks to the steel skeleton as applied to mill and factory types of buildings.

The old factory, machine-shop and foundry buildings were, of course, largely of wood construction with brick walls. The fire hazard in many factory buildings, such as glass-furnace buildings, foundries, etc., was very great. There is still a saying among the glass people, "three fires and then a steel building." With a combination of timber and rod construction some long-span roof trusses were used. Where the temperatures are high the wood deteriorates very rapidly.

The coming of steel construction introduced the overhead electric crane and with it the ability to handle great loads with ease. With the old, wooden, short-span girder construction, the capacity to handle heavy loads was very limited. The overhead electric crane is now entirely indispensable in the great steel-mill buildings, machine-shops and foundries.

*Chief Engineer, Pittsburgh Bridge & Iron Works, Pittsburgh.

The construction of conveyors of various types, and the outside yard crane runway for the economic handling of material, has become one of the most essential factors of modern manufacturing. We could not now consider the old-fashioned methods of storing and handling material by human labor, and the old crude machinery. The modern factory building made of saw-tooth, monitor type, or drop-bay construction can be extended in any direction, and in itself is the very essence of simplicity in steel construction. It permits of the best possible lighting conditions and also of very economical construction. We find factories covering many acres of ground under a single roof.

The steel-frame, steel-sash, and metal-clad or corrugated-covered buildings have come to stay, and if properly cared for will give long and substantial service. Some serious efforts have been made to use concrete girders for the supporting and carrying of moving loads, and some of these ended disastrously. Concrete is now relegated to floor slabs, curtain walls and foundations, where it belongs. The construction of long-span buildings with cranes carrying up to 150 tons is almost as great a marvel as the modern sky-scraper.

C. N. HAGGART:* The Peoples Bank building, here in Pittsburgh, depends upon the floors and walls entirely for resistance to wind, while, in the Arrott building, steel portal bracing is used to a considerable extent. I believe the latter is a much stiffer and more stable building on that account. The foundations of these two buildings are designed on spread footings, though I understand concrete piles were used in some portions of the Arrott building.

*Consulting Engineer, Pittsburgh.

A RECENT DEVELOPMENT OF ROLLED STRUCTURAL SECTIONS*

By A. E. Crockett†

INTRODUCTION

That there may be no doubt about the sections indicated by the title of this paper, I will tell you at the outset that they are the J. & L. "Junior" beams.

There are usually three questions involved in any product of merit:

1. Is the product right?
2. Will it fill its intended purpose?
3. Does it meet modern economic demand?

A combined answer to all of these could be summed up in the single word "yes"; but who ever heard of an engineer ever being satisfied with such brevity, and in particular, the structural engineer? A realization of this fact caused long hours of reflection, for I would not have you go away entirely unsatisfied.

One of the natural questions relative to the product is, "How is it produced?" To enter into a detailed account of all the steps involved, from the time the ore is charged into the blast-furnace to the moment when the finished beam comes from the last pass of a modern continuous bar mill, would consume more time than is permitted for this paper; therefore, to answer the first question, we will consider the research work that has been performed under the direction of Professor Milo S. Ketchum, who needs no introduction to this audience.

Naturally the engineers of our corporation delved deeply into the functions of these sections, testing them in every known manner, and all that they discovered was fully substantiated by the report from Professor Ketchum, an abstract of which it is my privilege and pleasure to present to you.

*Presented at "Civil Engineering Conference," November 4, 1926. Received for publication January 10, 1927.

†Manager, Bureau of Instruction, Jones & Laughlin Steel Corporation, Pittsburgh.

PROFESSOR KETCHUM'S REPORT OF TESTS

The tests were planned to develop such properties of the light I-beams as would make it possible to compare these beams with I-beams of standard section. Four series of tests were made as follows:

Tests for strength under vertical flexure.

Tests for sidewise buckling of compression flange.

Tests for resistance to failure by compression of web over bearing block.

Tests for resistance to diagonal buckling of web.

Tests for Strength under Vertical Flexure. The beams were tested in pairs, the upper flanges of the beams being stayed together with 3- by ⅛- by 12-inch steel plates, welded to the top flanges and spaced 12 inches from center to center. Six-inch beams were tested with spans of 6 feet and 12 feet; while 10-inch beams were tested with spans of 10 feet, 12 feet, and 20 feet. The loads were applied at the one-third points of the beams in all flexure tests. The ultimate fiber stresses for the six-inch beams varied from 51,200 pounds per square inch to 53,900 pounds per square inch; while the ultimate fiber stresses for the 10-inch beams varied from 43,300 pounds per square inch to 47,000 pounds per square inch. The yield-point stress as taken from the deflection diagrams for the six-inch beams varied from 33,600 pounds per square inch to 35,500 pounds per square inch, while the yield-point stress for the 10-inch beams varied from 20,900 pounds per square inch to 28,100 pounds per square inch. The modulus of elasticity of the steel as determined from the deflections varied from 27,200,000 to 31,200,000 pounds per square inch for the six-inch beams, and from 21,600,000 to 30,000,000 pounds per square inch for the 10-inch beams.

Tests for Sidewise Buckling. Tests of the six-inch J. & L. "Junior" beams were made with the beams unrestrained, with loadings at the two outer quarter points. The ultimate strengths of four six-inch beams with six-foot span varied from 21,700 to 26,300 pounds per square inch, with an average stress for four beams of

24,100 pounds per square inch. The ultimate stress from the formula, $f_1 = 40{,}000 - 60\,\frac{ml}{r}$, called formula (1), is 28,000 pounds per square inch. The ultimate strengths of two six-inch beams with 10-foot span were 16,200 and 17,600 pounds per square inch, while the ultimate stress from formula (1) is 20,000 pounds per square inch. The ultimate strengths of two 10-inch beams with eight-foot span were 27,100 and 28,500 pounds, while the ultimate strength from formula (1) is 30,400 pounds per square inch.

Six-inch and 10-inch beams were also tested with spherical bearings as used by Moore.* The ultimate strengths of two six-inch beams with six-foot span were 36,000 and 44,600 pounds per square inch, while the ultimate stress by formula (1) is 28,000 pounds per square inch. The ultimate strengths of three six-inch beams with 10-foot span varied from 21,200 to 36,000 pounds per square inch, with an average of 30,200 pounds per square inch, while the ultimate strength by formula (1) is 20,000 pounds per square inch. The ultimate strengths of four 10-inch beams with eight-foot span varied from 23,600 to 27,000 pounds per square inch, with an average of 25,000 pounds per square inch, while the ultimate strength by formula (1) is 30,400 pounds per square inch. The ultimate strengths of four 10-inch beams with 10-foot span varied from 26,400 to 28,900 pounds per square inch, with an average stress of 27,600 pounds per square inch, while the ultimate stress by formula (1) is 28,000 pounds per square inch.

The above data are summarized in Table I.

The allowable fiber stress for a beam without sidewise restraint may be calculated by the formula, $f_1 = 16{,}000 - 120\,\frac{l}{b}$, called formula (2).

Formula (2) for a six-inch beam gives an allowable fiber stress, for a six-foot span, of 11,300 pounds per square inch, and, for a 10-foot span, of 8200 pounds per square inch, while for a 10-inch beam there will be an allowable fiber stress for an eight-foot span of 11,200 pounds per square inch, and for a 10-foot span of 10,700 pounds per square inch.

*University of Illinois, Engineering Experiment Station, Bulletin 68.

TABLE I. TESTS OF BEAMS WITHOUT SIDEWISE RESTRAINT

Test	Number of beams tested	Depth of beam inches	Span feet	Average maximum fiber stress pounds per square inch	Fiber stress $40,000 - 60\frac{ml}{r}$ pounds per square inch
E	4	6	6	24,100	28,000
E	2	6	10	16,900	20,000
D	2	10	8	27,500	30,400
G	2	6	6	40,300	28,000
G	3	6	10	30,200	20,000
G	4	10	8	25,000	30,400
G	4	10	10	27,600	28,000

By comparing the allowable stresses as given by formula (2) with results of the tests, it will be seen that the beams will have a factor of safety greater than two, excepting for one six-inch beam with six-foot span, and one six-inch beam with 10-foot span, where the factor of safety is greater than 1.9. For the beams tested under conditions similar to those used by Moore,* the factors of safety are considerably greater than two.

The failures of the beams when tested for sidewise bending were elastic failures where failure could have been prevented by a small restraining force. The tests would therefore indicate that the six-inch and 10-inch beams will be amply safe against sidewise bending if designed in accordance with the standard practice for the design of I-beams.

Tests for Resistance to Failure by Compression of Web over Bearing Block. Tests were made of six-inch beams with bearing blocks 1.20 and 1.92 inches wide, while tests were made of 10-inch beams with bearing blocks 1.20, 1.92, and 2.96 inches wide. The ultimate stresses in bearing in the web as calculated by the Hudson formula (3) and the Carnegie formula (4) are given in Table II. The ultimate stresses when calculated by the Carnegie formula for the six-inch and the 10-inch beams, when considered separately, check very closely, although the six-inch beams were about 20 per cent. stronger than the 10-inch beams. The stresses given by the Carnegie formula appear to be elastic-yield values. These tests would appear

*University of Illinois, Engineering Experiment Station, Bulletin 68.

to be an excellent check of the Carnegie formula. These tests would indicate that J. & L. "Junior" beams may be designed for bearing by using the Carnegie formula.

TABLE II. TESTS OF BEAMS FOR COMPRESSION IN WEB OVER BEARING BLOCK

Depth of beam inches	Number of tests	Width of bearing block inches	Average shear pounds per square inch	Maximum bearing stress, pounds per square inch, Hudson formula	Maximum bearing stress, pounds per square inch, Carnegie formula
6	2	1.20	12,500	63,600	27,300
6	2	1.92	16,650	52,800	29,600
10	2	1.20	8,400	70,300	23,000
10	2	1.92	10,770	56,200	24,200
10	2	2.96	12,100	40,800	22,200

Tests for Resistance to Diagonal Buckling of Webs. The average shears on the six-inch and the 10-inch J. & L. "Junior" beams are approximately 85 per cent. of the maximum shears. The tests for buckling show that these beams behaved in the same manner as do standard beams under similar conditions. The six-inch beams gave ultimate stresses about 20 per cent. greater than did the 10-inch beams.

The exact analysis of buckling action is complicated, but the following approximate solution is in common use.*

A narrow strip of web making an angle of 45 degrees with the horizontal axis of the beam is regarded as a column carrying an average compressive stress equal to the shearing stress at the neutral axis. The length of the column is taken as $h \times \sqrt{2}$ where h is clear depth of beam. The web is thin and the slenderness ratio is large and Euler's formula for columns may be used. Euler's formula for fixed-end columns is, $s = \dfrac{4\pi^2 \times E}{\left(\dfrac{L}{r}\right)^2}$; $= \dfrac{1.64\ E}{\left(\dfrac{h}{t}\right)^2}$, called formula (6).

The maximum shear at the neutral axis for buckling then is given by formula (6).

For the six-inch beam, the maximum shear for buckling will be, from (6), $s = 24{,}100$ pounds per square inch.

*University of Illinois, Engineering Experiment Station, Bulletin 86.

For the 10-inch beam, the maximum shear for buckling will be, from (6), $s = 13{,}700$ pounds per square inch.

The average shearing stress on the light beams is approximately 86 per cent. of the maximum shearing stress. In the tests for buckling, the maximum shearing stress for the 10-inch beams was 22,000 pounds per square inch, while the maximum shear for the six-inch beams was 30,000 pounds per square inch.

These stresses appear too high when compared with the ultimate stresses given by Euler's equation. The following supplementary tests would indicate that the shearing stresses obtained in testing the light beams for buckling are a better measure of the resistance to buckling of the webs of the light I-beams than are the values for shear given by equation (6).

Short sections of 10-inch and six-inch J. & L. "Junior" beams were tested for ultimate compressive stress as columns. The section of the 10-inch beam was 0.835 inch wide and 0.167 inch thick and carried a maximum load of 2730 pounds, which gives an ultimate fiber stress in compression of 20,000 pounds per square inch. The section of the six-inch beam was 0.515 inch wide and 0.125 inch thick and carried a maximum load of 2050 pounds, which gives an ultimate fiber stress of 32,000 pounds per square inch. Tests made with specimens in which the upper flange was cut off and the top of the web ground to a curve gave values, respectively, 70 per cent. and 67 per cent. of the values of the specimens when tested with both flanges, which checks the theoretical ratio of Euler columns with fixed ends and with one round end.

It is interesting to compare the above shearing stresses with the shearing stresses in beams tested for compression in web over bearing blocks.

From Table II, the maximum shearing stresses in the six-inch beams were 19,600 and 14,700 pounds per square inch, while the maximum shearing stresses in the 10-inch beams were 12,600 and 14,200 pounds per square inch. These beams failed over the bearing blocks and not by buckling alone. The larger shearing values are for the wider bearing blocks. From this comparison, it would appear that the strength of the six-inch and 10-inch beams in shear will be considerably above the ultimate buckling strength as given by formula (6). These tests would indicate that J. & L. "Junior" beams

may be designed for resistance of the web to buckling, by the standard formulas used for rolled beams.

Conclusions. The results of these tests may be briefly summarized as follows:

1. Tests of J. & L. "Junior" I-beams, when tested in pairs with the upper flanges of two beams fastened together by means of stay plates spaced 12 inches from center to center, gave ultimate strengths with stresses well above the yield-point of the steel, and the beams behaved in the same way as do standard I-beams when tested under similar conditions.

2. The J. & L. "Junior" I-beams, when tested for crushing in the webs over bearing blocks, gave unit stresses which checked closely with the unit stresses in webs of standard beams when tested under similar conditions.

3. In all tests of J. & L. "Junior" I-beams, the flanges and webs worked together. The material in flanges and web of each beam was of uniform character and physical properties. The tests showed that the webs were effective without distress or distortion under normal working stresses. The tests indicate that the webs of J. & L. "Junior" I-beams are more effective in resisting buckling stresses than are the webs of standard beams.

4. Tests of J. & L. "Junior" I-beams with top flange unsupported gave results similar to the results, when properly reduced, that were obtained for eight-inch standard beams, but were relatively somewhat less stiff than the larger standard beams. The tests indicate that J. & L. "Junior" I-beams will have an ample margin of safety where the loads for beams with unsupported top flanges are calculated by the standard formulas for standard I-beams.

Briefly, the tests indicate that J. & L. "Junior" I-beams act in a normal fashion and that these beams may be designed and have their safe loads calculated by means of the standard formulas used by engineers for the design of standard I-beams.

APPPLICATIONS AND TESTS

The first question propounded at the beginning of this paper has been answered by the above presentation of Professor Ketchum's analysis of the "Junior" beams. We will now consider the other questions.

Frequently it will happen to the structural designer that he has to take care of a comparatively small load which is to be supported on a long span, as in floor construction, the purlins of roofs, and girts of the sides of buildings. In such cases, he may be compelled to use a beam or channel far too heavy for the load, because the section that could be bought and would give him the required section modulus deflects too much under the load. He has to use a section of a greater height, and with that a greater weight. This condition has been due to the fact that I-beam and channel sections were not designed to conform to the requirements of the building trade, but were designed so that they could be rolled into a shape which would permit the section to leave the finishing rolls without any buckling of webs, so that the edges of the flanges were fully formed and the sections were free from internal stresses.

The laws of flexure are such that the deflection of a beam is inversely proportional to the height of the beam. For the same span, loading, and allowable stress, the beam of the greatest height will give the least deflection. It is generally known that the deflection of beams should not be greater than 1/360 of the span; otherwise the plaster in the ceilings would crack. For 16,000 pounds per square inch allowable stress, the span of the beam should be 24.25 times the height, and for 18,000 pounds per square inch allowable stress, 21.5 times the height of the beam to fulfill the aforementioned condition, provided that the top flanges of the beam are braced laterally.

The designer, as a general rule, in cases where no plaster is connected with his structure, also will hesitate to use smaller heights of beams than obtained by the rules mentioned, because he is aware of the fact that it is not economical to use too small heights.

Taking, for instance, the standard nine-inch, I-beam sections, the following data for a maximum span will be found in the tables of structural handbooks:

Weight pounds	Section modulus	Allowable load for $f = 16{,}000$ lbs. per sq. in. pounds	Allowable load for $f = 18{,}000$ lbs. per sq. in. pounds
35	24.7	14,500	18,400
30	22.5	13,200	16,800
25	20.3	11,900	15,100
21.8	18.9	11,100	14,100

The maximum span of the nine-inch beam is $\frac{9 \times 24.25}{12} = 18.2$ feet for 16,000 pounds per square inch fiber stress, and $\frac{9 \times 21.5}{12} = 16.1$ feet for 18,000 pounds fiber stress. The variation in the above loads from 11,100 to 14,500 pounds and 14,100 to 18,400 pounds is a small one, considering the various kinds of loading to which floors of buildings are subjected.

If the designer is fortunate enough to have a load requiring a section modulus within the limits of 18.9 to 24.7 inch^3, he no doubt will choose a section that is economical by taking one of the standard beams; however, it frequently will happen that the load to be taken care of is either greater or smaller than carried by standard beams on a length of span and the section that is most economical for it. No particular hardship is encountered when the load is too great, as two or more beams can be used, or the spacing of the beams can be reduced. Sections of a greater height can also be used, which tends to still greater economy where this is not a cause for a greater height of the whole building; but, if the load be smaller, the designer is simply out of luck. He will choose the smallest weight section of the height that gives a deflection not exceeding 1/360 of the span. Of course, it is possible to use a section of slightly smaller height than $\frac{1}{24.25}$ of the span for 16,000, and $\frac{1}{21.5}$ of the span for 18,000 pounds per square inch. As the load is smaller, the stress is proportionately less and the deflection might still be within the required limit; but this requires trial figuring and, in most cases, additional figuring, and the amount of saving frequently is doubtful in such cases.

Returning to our example, it will be apparent that if, in the nine-inch beams, a section could be rolled with a section modulus of only one-half or one-third of the lightest standard nine-inch beam which weighs 21.8 pounds per lineal foot, and the weight of this section would be also about one-half or one-third of the 21.8-pound section, the designer could choose his section economically in a far greater range of loadings on given spans.

The J. & L. "Junior" beams, which are rolled in heights from six to 12 inches (including 11 inches, for which there is no standard section on the market at present), give section moduli about one-third of the lightest standard beams of the same group, and they also weigh only about one-third as much. As an example, the lightest nine-inch beam weighs 21.8 pounds; its section modulus is 18.9 inch^3. The nine-inch J. & L. "Junior" beam weighs 7.23 pounds per lineal foot and its section modulus is 5.63 inch^3—almost one-third of the 18.9 inch^3.

The J. & L. "Junior" beams also had to be designed so that a clean and straight section without internal stresses could be obtained. Advanced engineering, rolling-mill design, and mill practice make it possible to roll beams of such small thicknesses as these beams show, with comparatively slight change in the temperature of the material from reheating furnace to cooling bed.

Comparing in our example of the nine-inch beams, the proportions of the section modulus to the weight, we find that the nine-inch standard I-beam,

$$\text{at 35 pounds has an } \frac{S}{w} = \frac{24.7}{35} = 0.706,$$

$$\text{at 30 pounds has an } \frac{S}{w} = \frac{22.5}{30} = 0.750,$$

$$\text{at 25 pounds has an } \frac{S}{w} = \frac{20.3}{25} = 0.812,$$

$$\text{at 21.8 pounds has an } \frac{S}{w} = \frac{18.9}{21.8} = 0.867.$$

The nine-inch J. & L. "Junior" has an $\frac{S}{w}$ of $\frac{5.63}{7.23} = 0.779$, which is about the average of the group. This shows that the distribution of the material in the section is what might be called a "happy me-

dium." It would perhaps have been possible to place more material in the flanges and less in the webs of the "Junior" beams, thus obtaining a higher ratio of $\frac{S}{w}$ and with it a seemingly greater economy; but another consideration—that of the shearing strength and buckling strength of the webs—was the cause for caution in this direction, and the comparison just made indicated that the "Junior" beams should compare well with standard beams as to shearing and buckling strength, as well as to carrying capacity as a whole, as has been shown in Professor Ketchum's report of tests.

In a great many instances our eyes teach us more than words, and the illustrations herewith will be instructive in showing the use of beams in place in modern steel structures.

A test was made in Milwaukee (Fig. 1) of 10-inch "Junior" beams, span 13 feet, spaced three feet, center to center; the loading

Fig. 1. Milwaukee Test.

was 650 pounds per square foot. The result of this loading was a deflection of 1¾ inches at the two center beams.

At Toronto, Ontario, four nine-inch "Junior" beams were tested (Fig. 2). They had a span of 17 feet, 6 inches, and were spaced two

Fig. 2. Toronto Test.

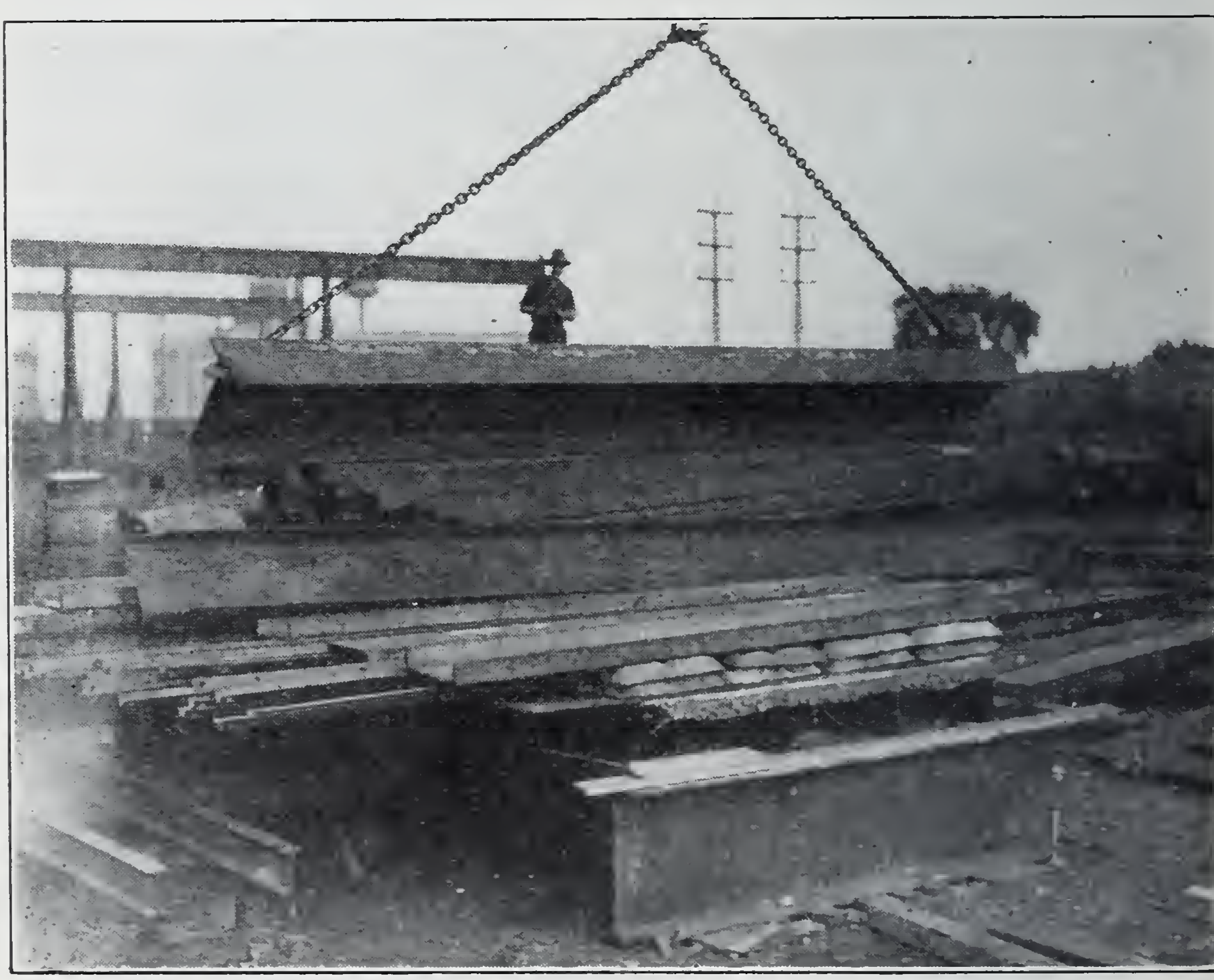

Fig. 3. Toronto Test.

feet, center to center. The beams were loaded to twice the rated live load (51.4 pounds per square foot). The deflection from this load was ⅜ of an inch. The allowable deflection for 1/360 of the span is 9/16 inch. This test was continued (Fig. 3) and a load of 31,498 pounds was applied. The beams carried 4.38 times the rated live load, or 225 pounds per square foot, with a dead load of 48½ pounds per square foot. The deflection under this load was 1⅜ inches minimum and 1⅝ inches maximum, the variation being probably due to placing the two I-beams as a concentrated load.

To determine the value of the "Junior" beams in a tile con-

Fig. 4. Test in Tile Floor.

structed floor, a panel 17 by 17 feet, consisting of 10-inch "Junior" beams, spaced 25 inches, was constructed The tile used was 12-inch "Natco" (two tile and a key). The slab when complete was ready for the surface floor. Seven pounds per square foot of sand was spread over the area to represent the flooring, and the total dead weight was 51 pounds (Fig. 4).

To obtain the deflection due to live load, 73 pounds per square foot of kegs of nails were placed as shown in Fig. 5. The deflection amounted to 1/16 inch. Upon removal of the kegs of nails, a complete recovery was obtained. Continuing this test, a load of 304

Fig. 5. Test in Tile Floor.

Fig. 6. Test in Tile Floor.

pounds per square foot of area was obtained by piling sacks of cement, as shown in Fig. 6. The deflection at the center of the "Junior" beam was 0.625 inches. The allowable deflection for ceilings, as repre-

sented by this panel, is 0.567 inches; with four times the working load on the panel, the deflection was still within the limits.

In the erection of the Penn-Lincoln Hotel, Wilkinsburg, Pa., a combination of "Junior" beams and hangers was used, as shown in Fig. 7.

To show the "Junior" beam used in header construction, to permit passage for piping and flues, Fig. 8 is presented, showing the Westfield School at Fort Wayne, Ind. Fig. 9 represents work in the Westfield School before placing the bridging.

The construction of a garage at St. Louis, Mo. (Fig. 10), shows the "Junior" beam with bridging placed. The "Junior" beams were

Fig. 7. Construction of Penn-Lincoln Hotel, Wilkinsburg, Pa.

carried on shelf angles. Standard channel sections were used for struts.

To indicate how "Junior" beams are carried in "Type A" hangers, a view (Fig. 11) of a building of the York Manufacturing

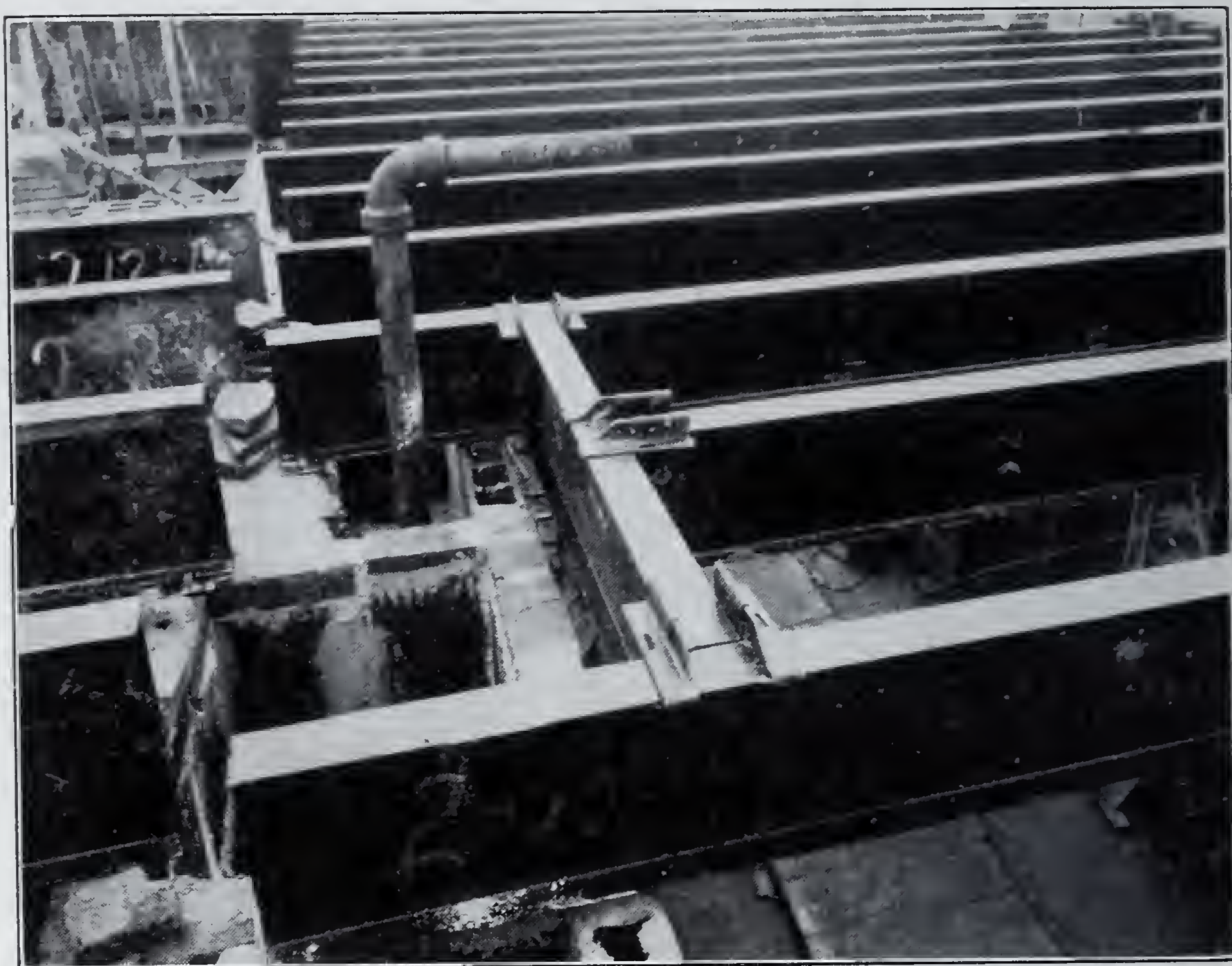

Fig. 8. Construction of Westfield School, Fort Wayne, Ind.

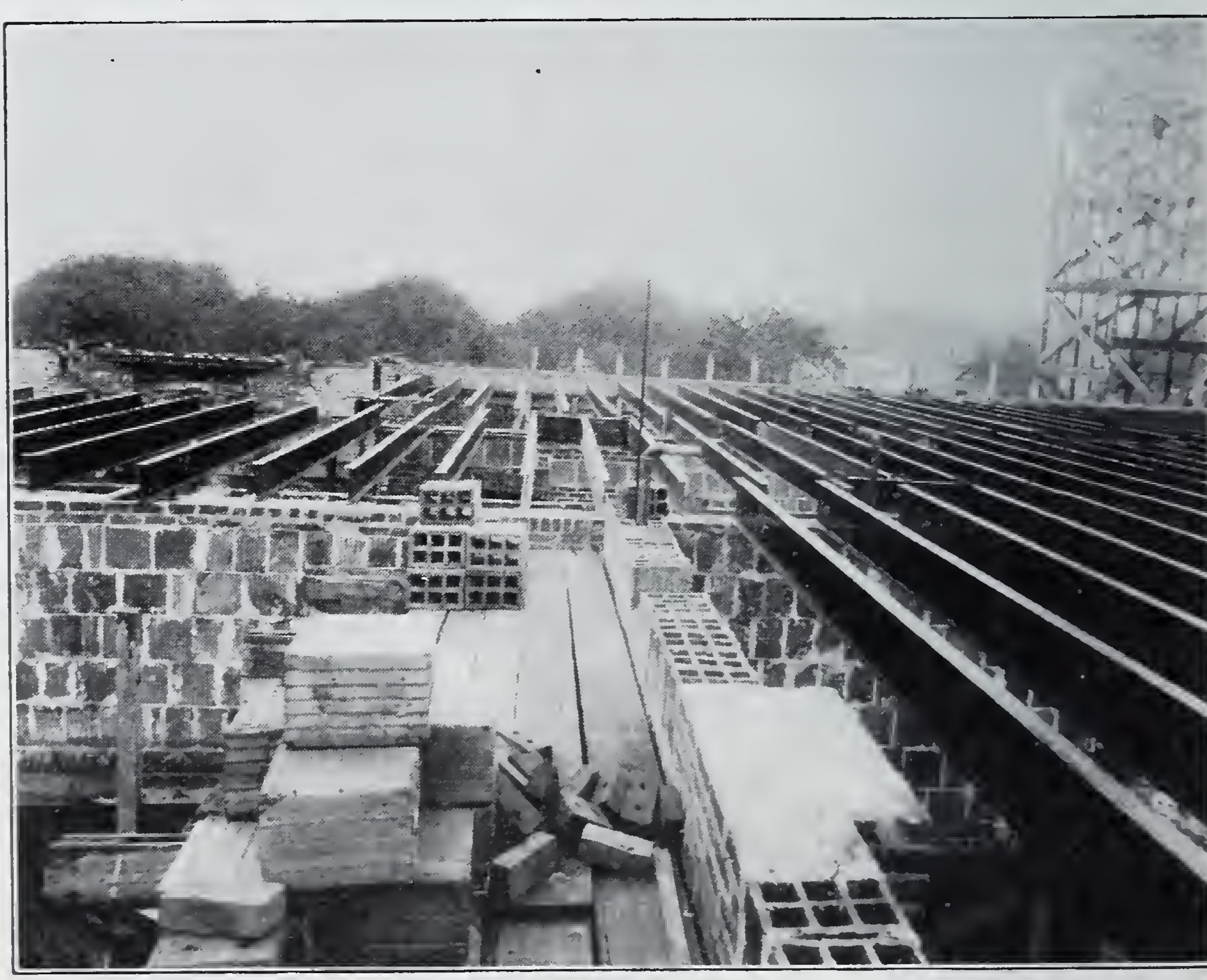

Fig. 9. Construction of Westfield School, Fort Wayne, Ind.

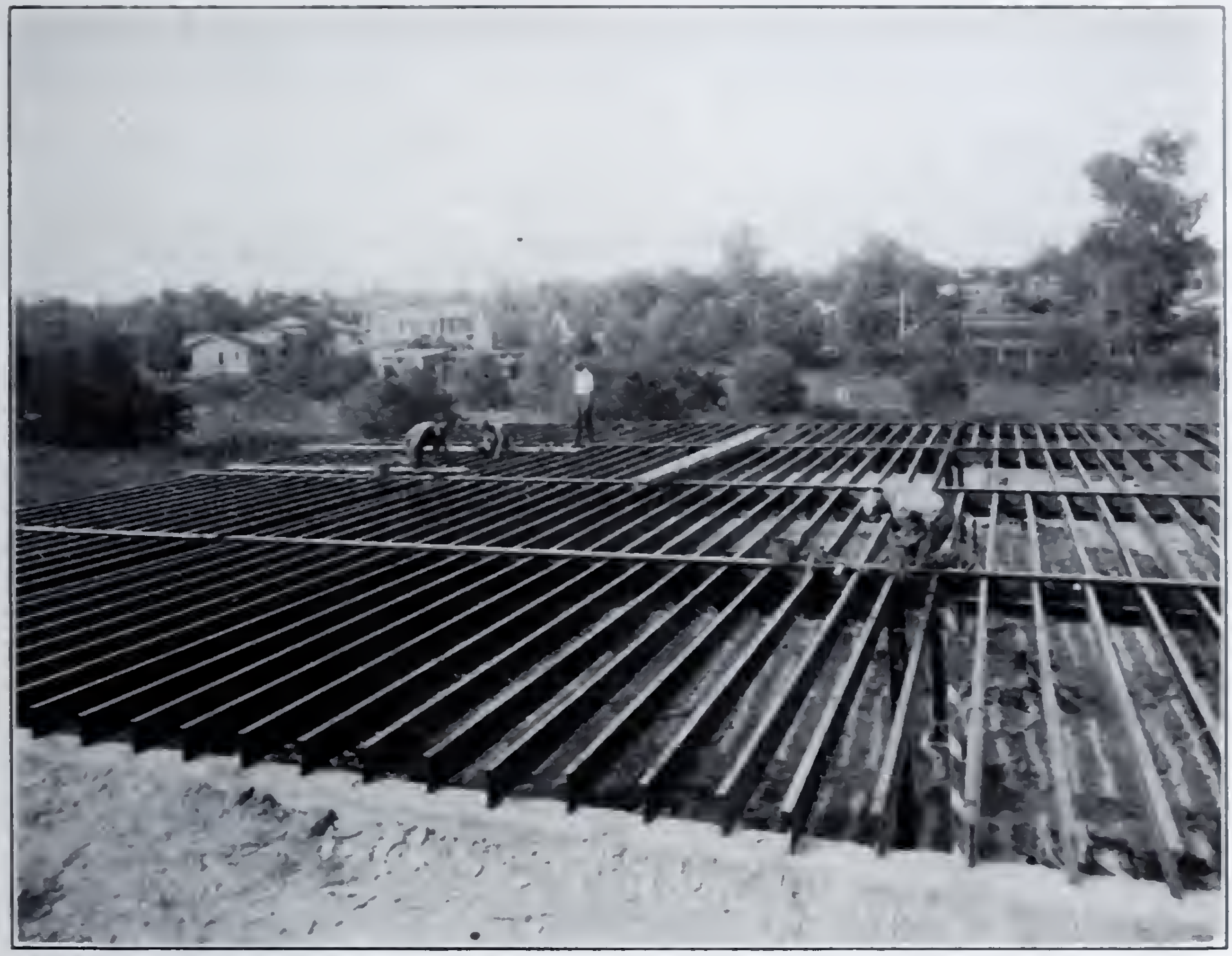

Fig. 10. "Junior" Beam in Garage Construction.

Fig. 11. Floor Construction, York, Pa.

Company, York, Pa., is presented. Note the metal lath in place for the concrete slab.

By using these beams for floor construction, the spaces between the beams are made smaller and the beams are used to their capacities and as near the allowable stress as can possibly be accomplished. The thickness of floor slabs for the same loads is thereby reduced and thus not only the weight of the steel that goes into the floor construction, but also the weights of the floor slabs themselves are reduced. This, in turn, saves steel in columns, and other materials such as concrete in the foundations, causing the number of piles to be smaller or the labor of excavation to be less. The advantage of light weight should not be overlooked; it saves labor in handling, transportation, and erection. The small thicknesses facilitate the punching of the beams for connections, and the cost is less than for standard beams. In many cases, it will be possible to make connections economically directly on the job by means of hand punches and hand shears.

DISCUSSION

J. S. Unger:* Tell us just what the "Junior" beam is. Not all of us know.

C. S. Boardman:† The word "Junior" has been selected as a trade name to signify that it is a smaller beam than the standard beam and to give it value in the trade as a trade name.

In the clay-tile test which Mr. Crockett mentioned in his paper, I am afraid he forgot to emphasize the fact that, in combination with the clay tile, it is for a full fire-proof construction. We feel that we have set the picture of the "Junior" beam for light floor construction and also for full fire-proof construction in combination with clay tile. As time goes on and our experiments are completed we will close that gap and use the "Junior" beam in design with other types of construction and with material now in use.

C. S. Davis:‡ The selection of the "Junior" beams for use in the Penn-Lincoln Hotel in Wilkinsburg rested, primarily, upon the

*Manager, Research Bureau, Carnegie Steel Co., Pittsburgh.

†Contracting Engineer, Junior Beam Division, Jones & Laughlin Steel Corporation, Pittsburgh.

‡Consulting Engineer, Ptitsburgh.

question of cost. Building costs are running so high that it was necessary to hold the cost of the finished structure as low as possible in this building. This beam was adopted in order to enable us to reduce the floor loads, with the consequent effect upon the structural frame, the size of the foundations, and the amount of excavation and concrete. The cost of floor construction with this beam was as low as any type of construction that could be used for this structure. It has proved entirely satisfactory and we have not been disappointed in our selection.

H. A. THOMAS:* I should like to ask if the method of rolling these beams is similar to that used with standard beams, or if vertical rolls are required in addition to the usual horizontal rolls. I have noticed that the flanges of the "Junior" beams do not have as much taper or draft as those of ordinary beams.

A. E. CROCKETT: The proportions are the same.

H. O. HILL:† I am quite familiar with the use of 1/8-inch metal in construction of transmission towers, but only when the structure is galvanized. In painted transmission towers we never use less than 3/16-inch metal. If a tower should fall, the power supply will be shut off and provoke some caustic remarks, but it seldom endangers life or property.

I am concerned regarding beams with 1/8-inch metal when used in open building construction where life and property are largely at stake. It seems to me that there is quite a hazard in regard to corrosion and I have been wondering if some thought has been put upon that subject before these beams have been offered for extensive use in building construction.

C. S. BOARDMAN: I think the point is very well taken indeed. The "Junior" beam is strictly a structural-steel beam, and we defeat our purpose if we put it in any structure where we feel it would be subjected to corrosion without proper protection. You speak of electric towers. We are going very slowly with any ideas of using the "Junior" beam in electric towers. The picture as now set is purely as

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†Transmission Engineer, Riter-Conley Co., Pittsburgh.

a floor member in a building. I feel that the engineers of this Society need have no fear that we will let it go out in any position where it will be subjected to excessive corrosion without adequate protection. The speaker has brought out the statement that the thickness of web is $\frac{1}{8}$ inch. The 12-inch beam is 0.17 of an inch, and the seven-inch is 0.12 of an inch. There is only one member in the whole group that is less than $\frac{1}{8}$ inch, and that is the six-inch section.

H. O. HILL: We know that in open construction, where steel is protected by paint, it often becomes rusted to such an extent that some of the metal is impaired before it is repainted. If beams with $\frac{1}{8}$-inch thickness of metal are used in open construction and permitted to rust, even slightly, the effective strength will be reduced by a very large percentage; great care should therefore be taken to prevent rust when these beams are used in open construction.

C. N. HAGGART:* I have been very much interested in these beams for use in floors in buildings. I understand they have been used in connection with buildings of all-steel construction. One thing has occurred to me. In recent years we have been flooded with different types of floor construction. Most of them are very light. We begin to think right away how much rigidity such floors will have and how much they will lend to the stiffness of the building. With the "Junior" beam type, it seems to me we would have a little more stiffness and rigidity and a little more to depend upon than with some other styles of construction on the market. I would like to ask if any consideration has been given to that point. Have connections to the main girders been designed with any idea of rigidity? You all know that in the recent storm in Florida it was very wonderfully demonstrated that the stiffness of the floors themselves helped a great deal toward distributing the wind stresses to all the columns and walls.

Also I would like to ask if the ends of the beams were secured in any way in these tests that were made.

V. C. WARD:† I am a newcomer in Pittsburgh. In answer to the question, I might say that yesterday I witnessed a loading test of a

*Consulting Engineer, Pittsburgh.

†Manager of Sales, Steel Construction Department, Jones & Laughlin Steel Corporation, Pittsburgh.

floor panel of "Junior" I-beam construction at our Aliquippa plant. The panel was carried on four steel columns located in the corners of a square 17 feet each way, columns having been set on concrete foundations, all sides of the panel being connected by 15-inch standard I-beams. Connected to two of these standard 15-inch I-beams were seven 10-inch "Junior" I-beams spaced two feet, one-inch centers. The end connection of the "Junior" I-beam consisted of 2½ by 2½ inches by ¼ inch angles, with two ⅞-inch rivets in the web of the "Junior" beams and two ¾-inch bolts connected to the web of the 15-inch beams. Between the "Junior" beams was a construction of tile arches, the tiles being 12 inches deep, and across the panel were two lines of ⅜-inch tie-rods to take the side-thrust of the tile arches, the tiles having been set in cement mortar.

Our calculated weight of this floor was 51 pounds per square foot, exclusive of the weight of the standard 15-inch beams. The "Junior" beams were figured for an actual live load of 70 pounds per square foot. Kegs of nails were distributed over the panel, giving us an actual distributed load of 73 pounds per square foot. Later, the kegs were removed and layers of cement sacks were placed on the surface of the panel until a superimposed load of 304 pounds was reached, and with this maximum load the actual deflection amounted to only ⅝ of an inch.

Many of you might be interested in going to see this test panel which was left with a maximum load applied. Seeing is believing, and it would give us a lot of pleasure to take any of you out there to-morrow or at any other time to see just what we have developed. It looks to us as though we have something new in the way of steel construction that you have all been waiting for for a long time.

W. W. Hendrix:* I have heard in the discussions mention made of the use of "Junior" beam for girts and purlins. The general discussion, however, has been in reference to its use in floor construction only. I believe most of those present do not seriously question its adaptability for this purpose. I should like to hear a little more elaboration with reference to its use as girts and as purlins.

C. S. Boardman: We have not developed the industrial type of the work quite as far as we have the floor systems, but we see no

*District Sales Manager, Pittsburgh Des Moines Steel Co., Pittsburgh.

reason why it should not be used in roof framing, under proper analysis. I do not believe I would use it in a building where any process or operation is such that it would bring about a quick corrosion; but, even so, with care and attention, the "Junior" beam is entirely proper.

F. M. McCullough:* I want to make one remark about testing slabs. When loading slabs with pig-iron or similar materials, great care must be used in order to obtain a uniform load across the slab. Unless the pig-iron is piled in separate piles, the load will arch toward the supports, giving a greater intensity of loading near the supports than at the center of the span. This condition will, of course, result in a very considerable decrease in bending moment as compared with that due to uniform loading. In some of the slides shown it seemed to me that this arch action existed.

The writer carried on a series of slab tests several years ago, the intensity of loading desired being at least 1500 pounds per square foot. The method used was to pile the pig-iron in separate piles four to six inches apart, with the successive layers cross piled. In order to prevent the piles from tipping, we placed horizontal sheets of expanded metal across all of the piles on the slab every 12 to 18 inches. In this way we were able to pile the pig-iron to a height of six to eight feet with very little arch action.

Robins Fleming:† I have been much interested in the paper presented and in this discussion. Professor Ketchum was quoted and I have a great respect for Professor Ketchum. What I am trying to get at is how are the "Junior" beams to meet Professor Ketchum's specifications. In some of them he calls for no material, except fillers, to be less than ¼ inch thick. In his latest specification for steel mill buildings he calls for the minimum thickness of rolled channels to be 0.18 inch. Most of our building codes specify the minimum thickness of material. Even where rolled sections are excepted it is doubtful if the writers foresaw as thin webs as those of the "Junior" beams. In transmission towers I know of nothing less than ⅛ inch in thickness being used, and they give that a coat of galvanizing that adds to the thickness.

*Professor of Civil Engineering, Carnegie Institute of Technology, Pittsburgh.
†Structural Engineer, American Bridge Co., New York.

A purchaser is not often an engineer, though he may employ one. An engineer who would not know discretion if he met it on the street would probably insist that the specifications be followed to the letter. I once had just such an experience. Some 10-inch I-beams were rejected because they were 0.23 inch thick, and therefore less than the ¼ inch minimum thickness of material called for by the specifications. A building inspector in a city department might make similar decisions. This has nothing to do with the merits of the "Junior" beams incased in concrete for floor construction, but a real difficulty may be met in making them comply with present building codes and specifications.

A. E. Crockett: I think we need not have any trouble about that since the American Institute of Steel Construction has started its work and included Professor Ketchum in its number, and they seem to be coming to this idea, not yet perfected by any means, and I think as we scientifically develop the real values of structural steel, specifications will be changed to express these values properly. I was lecturing at Princeton a few years ago when Professor Beggs passed the remark, "What is the matter with the steel industry; why doesn't it wake up?" I replied, "It is waking up and you teachers must grasp the fullness of the vision that is now before us." The whole thing is changing from one end of the steel industry to the other. There is hardly a week but something new is coming out. We are learning the truth of things because we are getting instruments to learn the truth. I believe that whatever may have been the restrictions in Professor Ketchum's specifications, or any other, it is only a question of time when we will get full light on economical progress in the production of buildings, as well as other steel structures.

C. S. Boardman: We will have Professor Ketchum's report printed in a very short time and we will be very glad to give you copies.

Mr. Lee Miller, chief engineer of the American Institute of Steel Construction, in his specifications permits the "Junior" beam in the floors of buildings. He has passed the "Junior" beam as a structural beam and has sanctioned its use as structural steel.

Robins Fleming: Have Mr. Miller's specifications been adopted?

C. S. Boardman: The specifications of the American Institute of Steel Construction are being adopted in a great many cities of the country. I realize that your objection is well taken from a sales point of view. It is one of the big features we will have to overcome in the sale of the "Junior" beam.

A. E. Crockett: Taking the first 50 cities in population, 70 per cent. of them have already adopted the specifications of the American Institute of Steel Construction.

R. P. Forsberg:* As a member of the Engineers' Society of Western Pennsylvania, I desire to express my appreciation for the courtesy that has been extended by the Jones & Laughlin Steel Corporation in furnishing this extremely interesting paper on a subject of such recent development. I noted on the slides just exhibited that some of the tests were made only last month, which shows that we are getting information of a very recent development. I believe that this is the maiden presentation of the "Junior" I-beam before an engineering society.

The engineering department of the Pittsburgh & Lake Erie Railroad has shown its interest and its confidence in the "Junior" I-beam by specifying it for use in a two-story office building to be located adjacent to our terminal freight station in Pittsburgh, the contract for which has just been awarded. It will perhaps be five or six weeks before the beams are in place, but I will at this time extend an invitation to any member of our Society who may desire to see them before the floor and roof of slabs are put on to call and inspect them, for our engineering department will take pleasure in exhibiting them.

P. W. Price:† In handling sections such as beams, where the lengths are perhaps as great as 20 or 30 feet, we sometimes find difficulty in getting the structural members through the shops and into the field and erected without very slight kinking or buckling. It

*Principal Assistant Engineer, Pittsburgh & Lake Erie Railroad, Pittsburgh.

†Principal Assistant Engineer, Bureau of Bridges, Department of Public Works, Allegheny County, Pittsburgh.

would look as though these very small sections might give some difficulty in that respect unless they are handled in a very careful manner; that is, with more care than these small sections usually receive.

C. S. Boardman: I can answer that by saying that we are now studying the problem of shipping beams to structural fabricators around the country. As far as we have gone we are bundling eight or ten beams together with steel bands, and in that way we feel that we will get very good shipping results. In the mill we are cutting to stock lengths at the present time and the mill is giving that a good deal of thought, handling them longer than 50 feet. We are now regularly handling them in 45-foot lengths.

FOUNDATIONS*

By George R. Johnson†

The foundation as a part of a structure is of paramount importance, for on it depends the security of the whole. The object of this paper is to give a general description of foundations, and it must be general, for the subject is so broad and complex that many of its interesting and important details can be treated, in such a short space, only in a superficial manner.

The problem before the engineer in determining the kind of foundation to be used can be separated into several factors or conditions to be satisfied. These conditions follow, and the type of foundation which satisfies them is the one to be used.

1. The magnitude and distribution of the loads to be supported.
2. The depth of a suitable bearing material.
3. The nature of the material above this bearing stratum.
4. The water-level at the site.
5. The surrounding conditions.
6. The economy of construction.

The first of these conditions is determined by the design of the superstructure, and is usually quite definite. The next three conditions—depth of suitable bearing, nature of the material above this, and the water-level—are determined by ground exploration such as boring or records of adjacent substructures. Nevertheless, there is a large question of judgment involved here. Borings, particularly wash borings, are not always definite; a hard-pan may have soft streaks or an indication of rock may be but a boulder. A material may vary in supporting power as its water content varies. Water-level may be changed by the building of future structures. Even the records of adjacent substructures may show elevations of strata differing sufficiently from those of the site under consideration to mean a change in the type of construction.

In a foundation the determining of depths is of great importance, for the area covered in proportion to the depth is usually rela-

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tively large. This means that a slight change in depth will make a large difference in total cost, so that the necessity of adequate exploration and skillful interpretation of its results can not be too strongly emphasized in considering a foundation project.

The surrounding conditions are also important. The character of the adjacent foundations and their support must be investigated. One kind of foundation might cause undermining and settlement, while another could be built safely. Thus, in a site which is in a locality underlaid by quicksand, and which is surrounded by buildings founded on top soil, a deep foundation can not be sunk by a single open excavation on account of the flow of the quicksand. The vibration of pile driving may damage adjacent structures. All factors must be considered; not only the immediate surroundings, but also the general locality, as influencing the relative availability of material.

The foregoing considerations are largely physical, and the economic condition determines how far they must be developed in selecting the type of foundation to be used. The value of the superstructure, its permanence, the required speed of construction, and the funds available, determine the cheapest foundation that can satisfy the physical condition of the site. Thus, for an exposition building, a timber grillage good for a year or two will suffice, while a 40-story office building will require concrete piers to bed-rock.

Foundations are generally classified in the following groups:

1. Spread footings.
2. Pile footings.
3. Open-method piers.
4. Pneumatic-method piers.
5. Combination open and pneumatic piers.

Spread footings are made by increasing the bottom surface of the loaded pier to such an area that the unit stress on the soil below it is within the safe bearing capacity of that soil. They are the common type for light buildings, but they are used also for the support of heavy loads. Their chief advantage is that they require little excavation, and that near the surface.

The methods used to increase the pier area are varied, and the more common types are illustrated in Fig. 1. The most common up until comparatively recent times was to step out the masonry of the

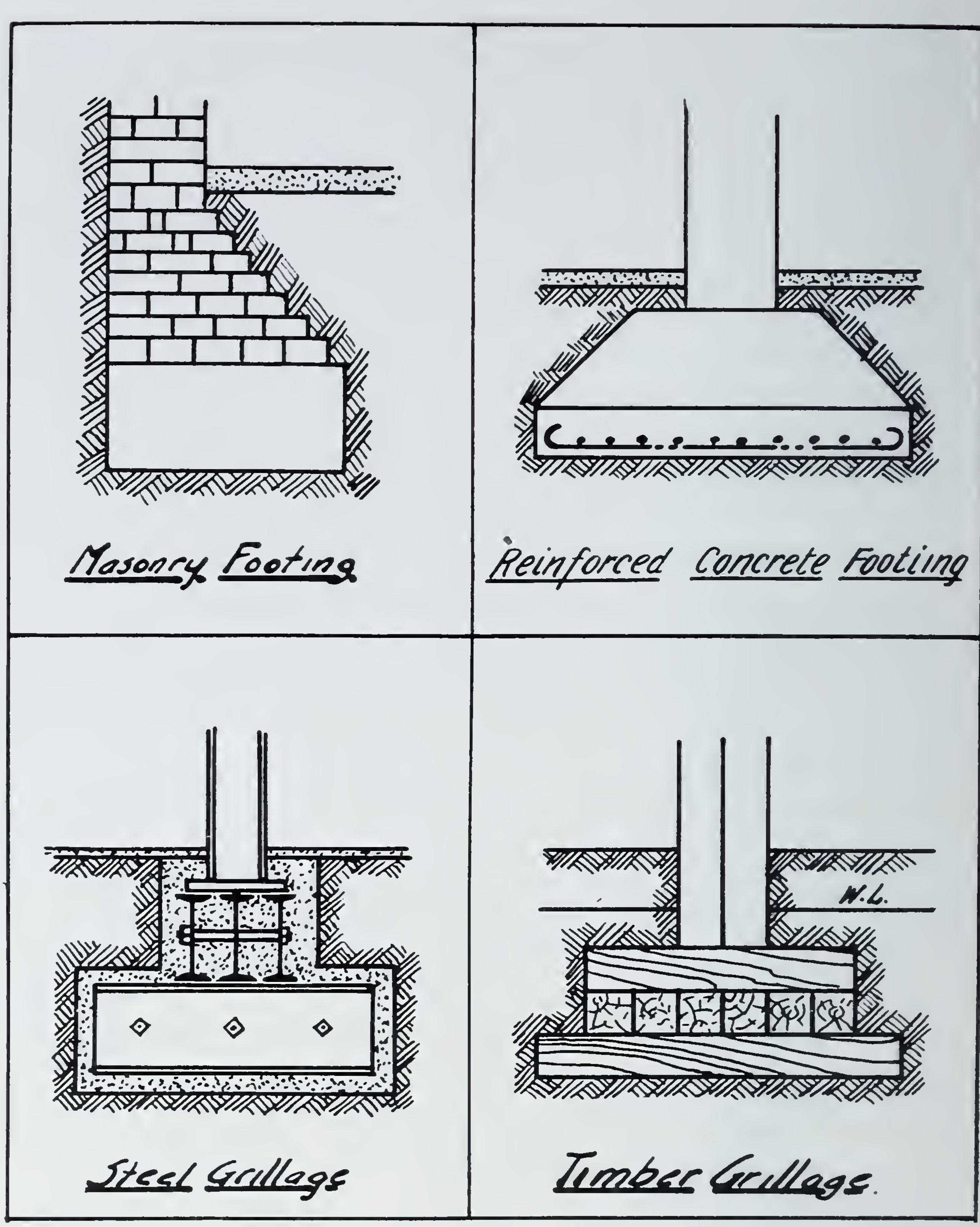

Fig. 1. Types of Spread Footings.

pier until sufficient bearing area was obtained. This required quite a depth for a heavy load, because the spread footing acted as a beam and masonry is low in tensile strength. To overcome this, inverted arches were built between adjacent footings. Where it is certain that the footing will always be below water-level, a grillage of wooden beams can be used, and many large bridge piers have in the past been founded on such a grillage. A wooden grillage is not suitable to support a

highly concentrated load because wood has a low resistance to crushing across the grain. For the reason of greater strength, steel and reinforced concrete are now almost universally used in spread footings of any size. Steel grillages are designed as separate tiers of beams and are incased in concrete to prevent corrosion. Reinforced concrete footings have been the subject of quite elaborate design, as this material is particularly suited to spread-footing construction, since it combines in itself the properties of a material having good value in tension and compression and is capable of being formed in any desired manner.

In a spread footing care must be taken that the soil is not overloaded—not only the bearing stratum, but also the strata below. If a layer of clay or compact gravel overlies a layer of quicksand or alluvium, the latter will determine the load that can be borne safely by the upper stratum. If the footing is eccentric, it should be so designed that the maximum bearing power of the soil is never exceeded.

A footing resting on two kinds of material should be designed so that the bearing on the weaker is not in excess. The effect of water should be determined, as the bearing power of materials varies with their content of water, and a future change in water-level may be the cause of settlement. If the footing is a wooden grillage it is necessary that it be always under water for preservation. In cold climates the footing should be below frost action, and in rivers it should be deep enough to be out of danger from scour. It is also advisable to consider the effect of future construction on the footings.

Pile footings are used when the soil at the bottom of the pier has not sufficient bearing capacity and it is inadvisable to excavate to a deeper stratum. They also have a particular value in marine and river work, as they permit a foundation to be placed from above the water surface, as in the case of a trestle or pier. Piles are made of sand, wood, concrete, or steel. There are two general classes, one of which supports its load by transferring it to the surrounding material by the friction of that material on its surface, and the other of which transmits its load directly to a firm stratum at its foot, acting as a true column. Fig. 2 is a diagram of a pile footing, the one shown being a friction pile. Fig. 3, from a photograph taken during the construction of the approaches of the Wheeling-Belmont bridge, shows a pile footing in place, but with the surrounding earth removed.

The cheapest type of pile is composed of sand. This is made by punching holes in the soil and ramming them full of sand. Sand will transmit compressive loads with very little lateral pressure, but the

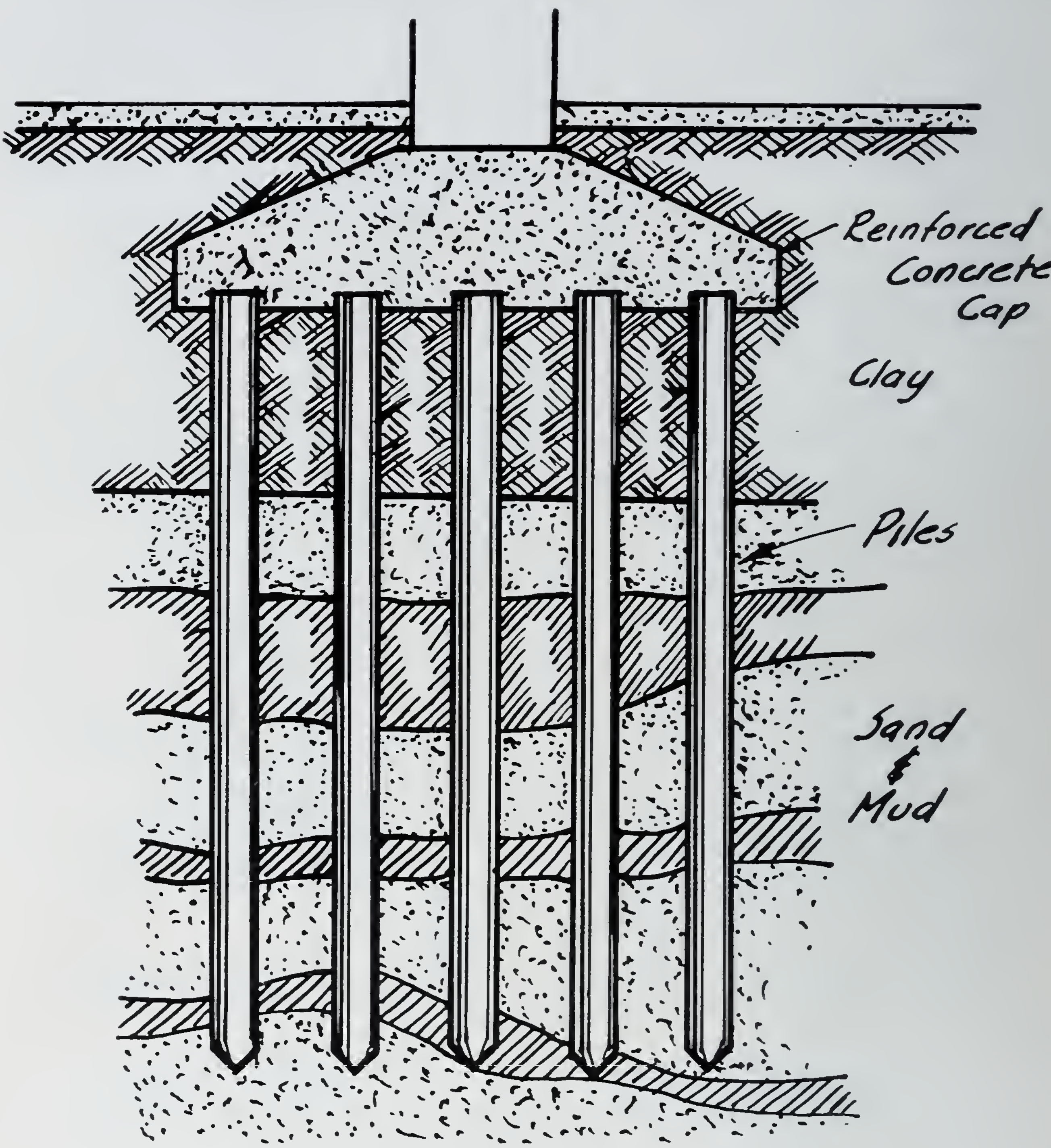

Fig. 2. Pile Footing.

action of this type of pile does not extend very deep, the depending on the nature of the soil penetrated.

In the past, wooden piles have been much used, and even at present they are in wide use. They are cheap, and if kept below water-level, they form a permanent piece of construction. They are driven by hammer, or jetted into the soil.

Wooden-pile construction is very rapid, and at the same time cheap, so that for temporary construction it has a particular field of importance. Fig. 4 shows a pile foundation at the League Island Navy Yard which contains 15,000 piles.

At the present time concrete piles are used to a great extent on account of their durability and because they have greater capacity than wood piles, particularly when acting as columns. There are two types

Fig. 3. Pile Footing, with Surrounding Earth Removed.

of concrete pile—the precast pile and the cast-in-place pile. The precast pile is, as its name implies, formed and seasoned above ground before driving. It is made in various shapes, but in general is a prism of concrete, reinforced against handling and driving stresses. Precast piles are sunk by a jet or by driving with a hammer, in the same way as wooden piles. There are several types of cast-in-place piles. Some are straight, some tapered, and some have a bulbous foot formed by ramming the wet concrete into the soil. They are, in general, formed

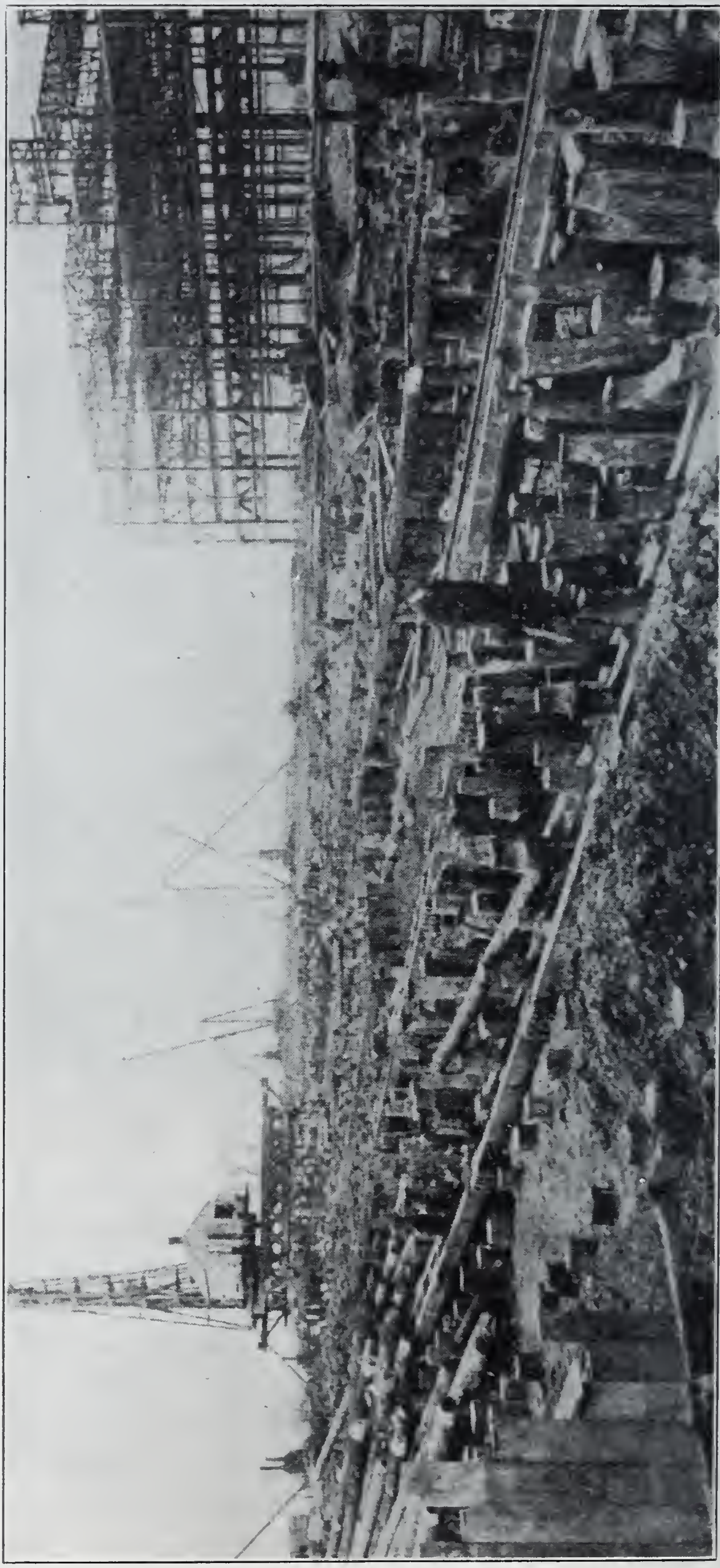

Fig. 4. Pile Foundation.

by driving a casing into the earth and filling it with concrete. Some types withdraw the casing; others let it remain.

Steel and cast-iron are to some extent used as piles, but their uses are for such specific purposes as pedestal and screw piles, which will not be discussed here, as they are practically obsolete.

Pipe piles—which are, in fact, pipe caissons—consist of steel pipes which are forced down by a hammer or jack, the material inclosed being excavated. A 16-inch pile of this type is capable of safely supporting 100 tons. The pipe can be thoroughly cleaned out and inspected. The bearing of the pile against its supporting strata is definite, and owing to this high supporting value the pipe pile is economical, as fewer than of other kinds are required to carry the load. Fig. 5 illustrates the use of pipe piles. The loads (indicated in tons) are column loads.

In choosing the type of pile to use, all the various factors entering into the situation must be considered. In the case of wooden piles, the water-level is of importance as determining the life of the structure. In the choice between wood and concrete, the durability and strength, as well as the economy of the structure, are deciding factors. The various types of concrete piles have points of superiority under certain conditions. Where a pile is to act as a column, a well reinforced precast pile is the best. This is also the case where jetting is to be used. In general, where there is a likelihood of any lateral stress, the precast pile is the best type to use. The cast-in-place pile may be more economical to use under certain conditions. Where the ground is soft, and friction piles are to be used, a tapered cast-in-place pile has advantages, and may be cheaper due to the lack of necessity for reinforcing. In a uniform soft mass such as alluvium, a pile with an enlarged foot may be cheaper due to increased bearing power per pile. Some cases are best taken care of with composite piles of which the lower portion is wood and the upper portion concrete.

When using pile footings, care must be taken to see that all piles have reached a good bearing stratum, or have penetrated far enough to develop sufficient frictional resistance. Piles must not be overdriven or driven against a hard stratum until they become shattered or broken. Piles acting as columns must be investigated as such, and where the soil is depended on for lateral support the effect of vibration, if present, should be taken into account. Proper clearance should

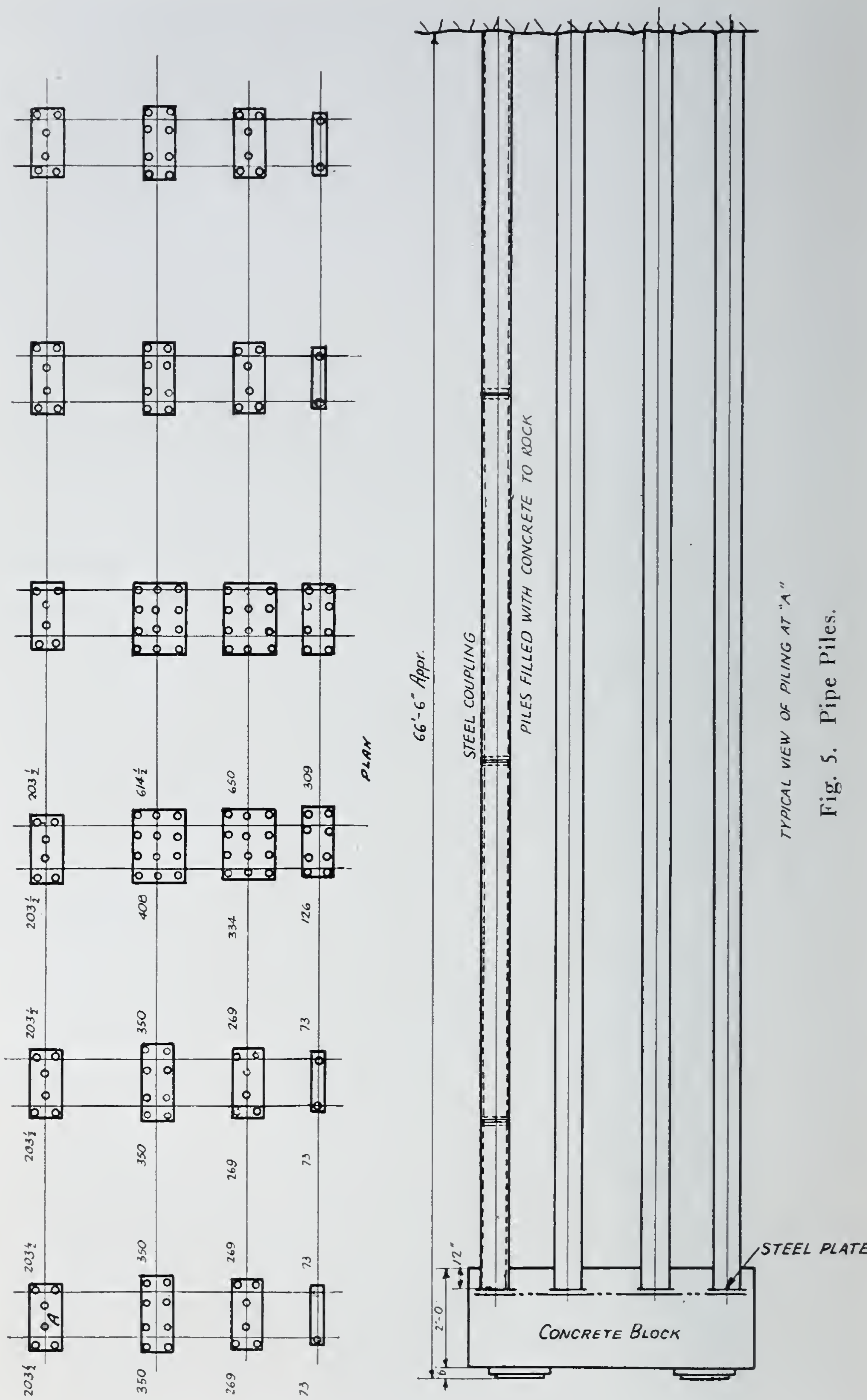

Fig. 5. Pipe Piles.

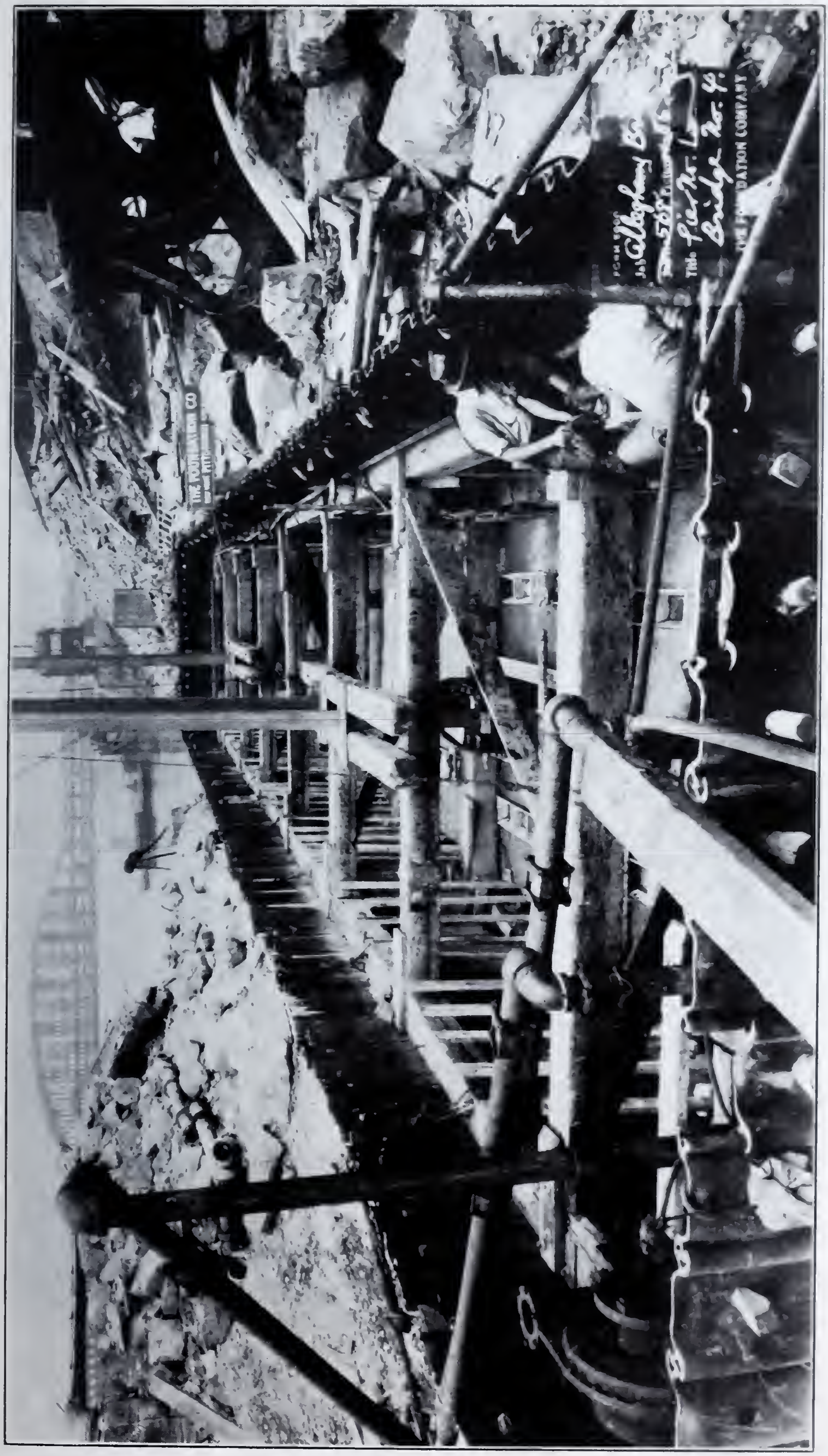

Fig. 6. Coffer-Dam.

be given piles to permit clear driving, for otherwise the last piles will not penetrate as desired, due to compression of the soil, which may later readjust itself and cause unequal settlement.

The open method of pier construction is used when it is necessary to place the foundation directly on a firm stratum. There are two general methods, the coffer-dam or sheeting method, and the caisson. (This paper will not deal with coffer-dams for marine or river work which are used to exclude water alone, but only with

Fig. 7. Interior of "Chicago Well."

coffer-dams which penetrate the earth to be excavated.) The two methods merge together so that it is sometimes difficult to say whether or not a structure is a caisson or a coffer-dam, but, in general, if the structure is integral and does not depend on the surrounding material for its unity it is a caisson; otherwise a coffer-dam.

Coffer-dams are constructed in various ways. Timber or steel sheet piling may be driven from the surface to a firm stratum, or, in the case of timber, carried down with the excavation. Fig. 6 shows a

Fig. 8. Construction of "Chicago Well."

sheet-pile coffer-dam used at Allegheny River bridge No. 4. It is desirable and often necessary in the case of a building foundation to

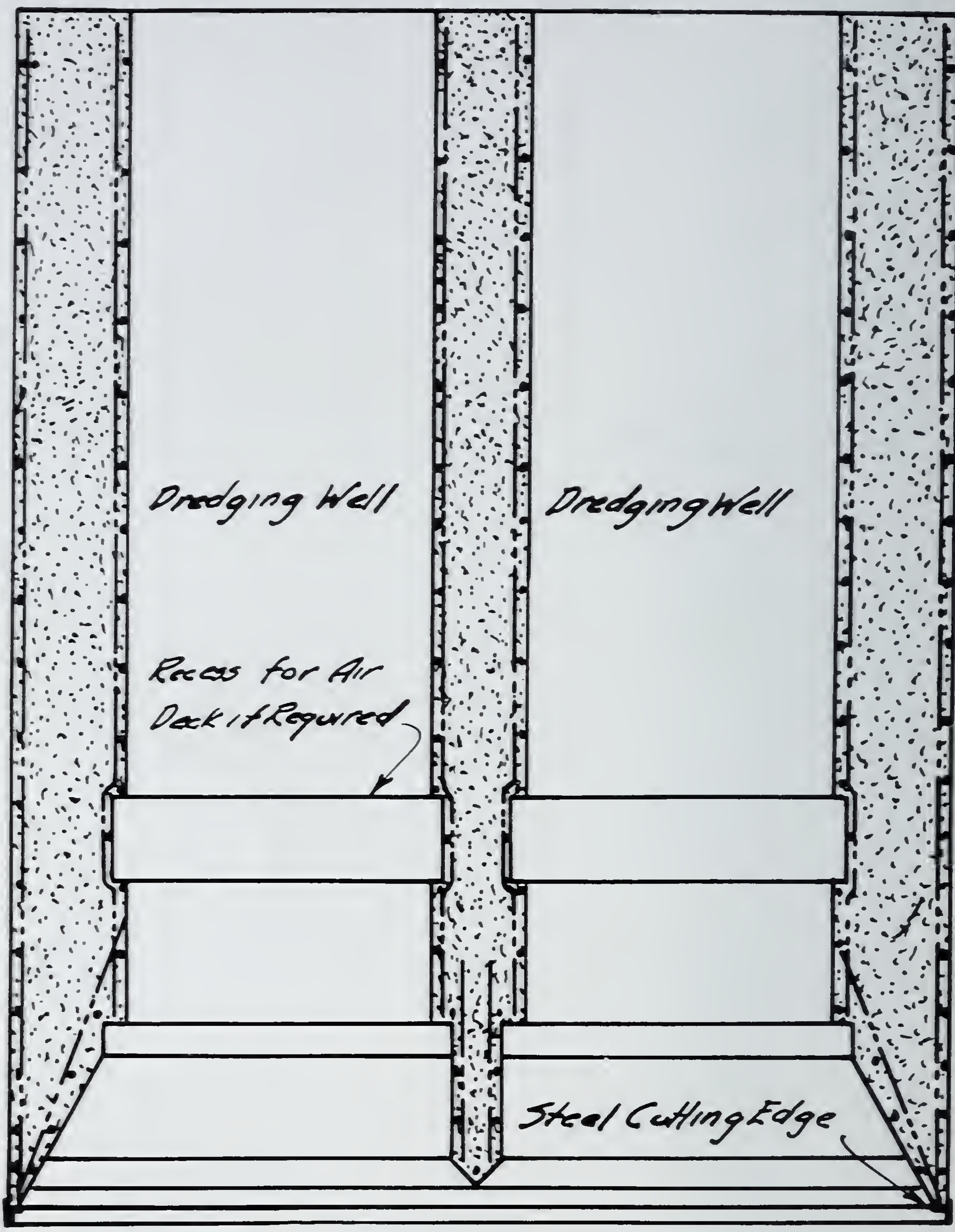

Fig. 9. Cross-Section of Open Caisson.

have the sheeting reach solid material in order to prevent shifting and consequent settling of adjacent structures. The coffer-dam process, if carried very deep, is known as the "open-well" method. The excava-

tion may be made in a series of coffer-dams, the lower being driven inside the upper after the upper section is excavated.

An important type of this kind of construction is the "Chicago well," which is applicable in a soil which is impervious to water and is stiff enough to support itself for a short depth—a stiff clay, for example. The well is dug in the clay for about four or five feet and then a section of lagging is put in. The process is repeated until the bearing material is reached. A variation of this, in soft material, is the use of a shield as in tunnel construction, but this is not common. Fig. 7 is an interior view of a "Chicago well" showing the lagging ready to be set into place. Fig. 8 shows the well in course of construction and the steel rings which support the lagging.

Open caissons are constructed of wood, steel, and reinforced concrete. They are used principally for bridge-pier foundations, and as such the wood and steel caissons are usually built with double walls to form pockets for weighting down. The caisson is an inclosure of walls with an open bottom, and is divided, for the purpose of transverse bracing, into compartments or dredging wells. The walls are thinned at the bottom to a cutting edge so that the caisson will sink as the material inside it is dredged out. Caissons may be built on shore, and have false bottoms placed to permit them to be floated to the site, or they may be built on a platform and lowered to place. If the expense of a coffer-dam is warranted, the site may be unwatered and the caisson built on the river bottom. Fig. 9 is a vertical section through an open concrete caisson. Fig. 10 is a view of the open caisson sunk in construction of coal-storage bins, intake, and condenser wells at the Cincinnati generating station. Fig. 11 is a view of the large open caisson sunk at Washington Navy Yard.

As the excavation proceeds inside the caisson, it is sunk. Caissons without pockets are sunk by weighting down with removable weights; concrete caissons are usually made heavy enough to sink without additional weight. Caissons with double walls have these filled with concrete or gravel. There is no ordinary limit to which an open caisson of this type may be sunk, and aside from economy this is its great advantage.

The open caisson has disadvantages which are overcome by the penumatic method. Aside from the danger to adjacent structures,

Fig. 10. Open Caisson.

due to undermining, open caissons are not economical to use in stiff clay or boulders. The pneumatic caisson has not these disadvantages and has the facilities for a thorough inspection of the bottom. The pneumatic caisson is based on the principle of the diving bell, and a type used in building foundations is shown in Fig. 12. A working

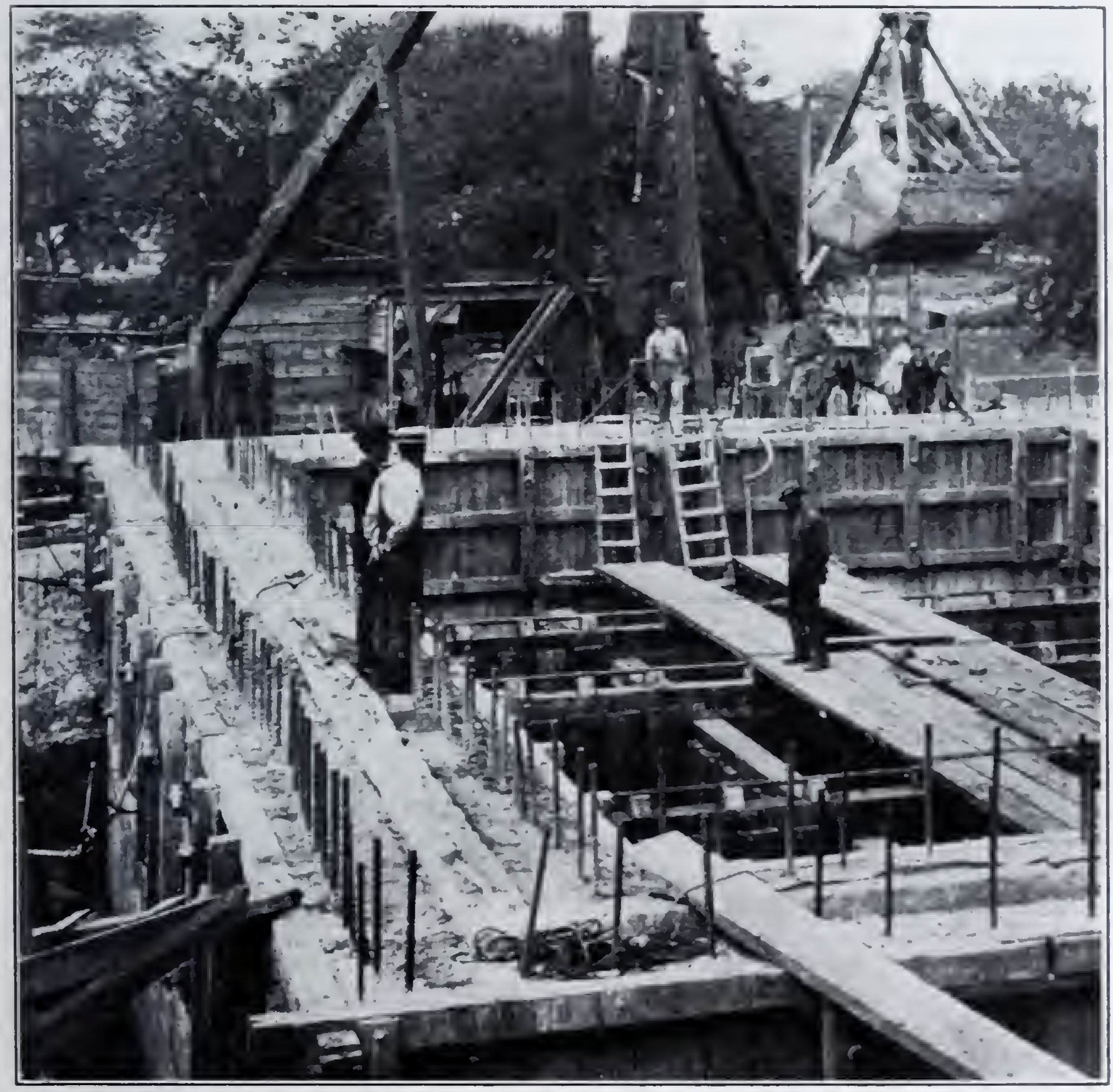

Fig. 11. Open Caisson.

chamber of wood, steel, or concrete is constructed on which the pier is built. This working chamber is bottomless, and access to it is by a shaft in the top closed by an air-lock which allows air under pressure to be retained in the working chamber as materials are removed. When the cutting edge is below the water-level, the working chamber is put under air pressure equal to about the head of water. This holds

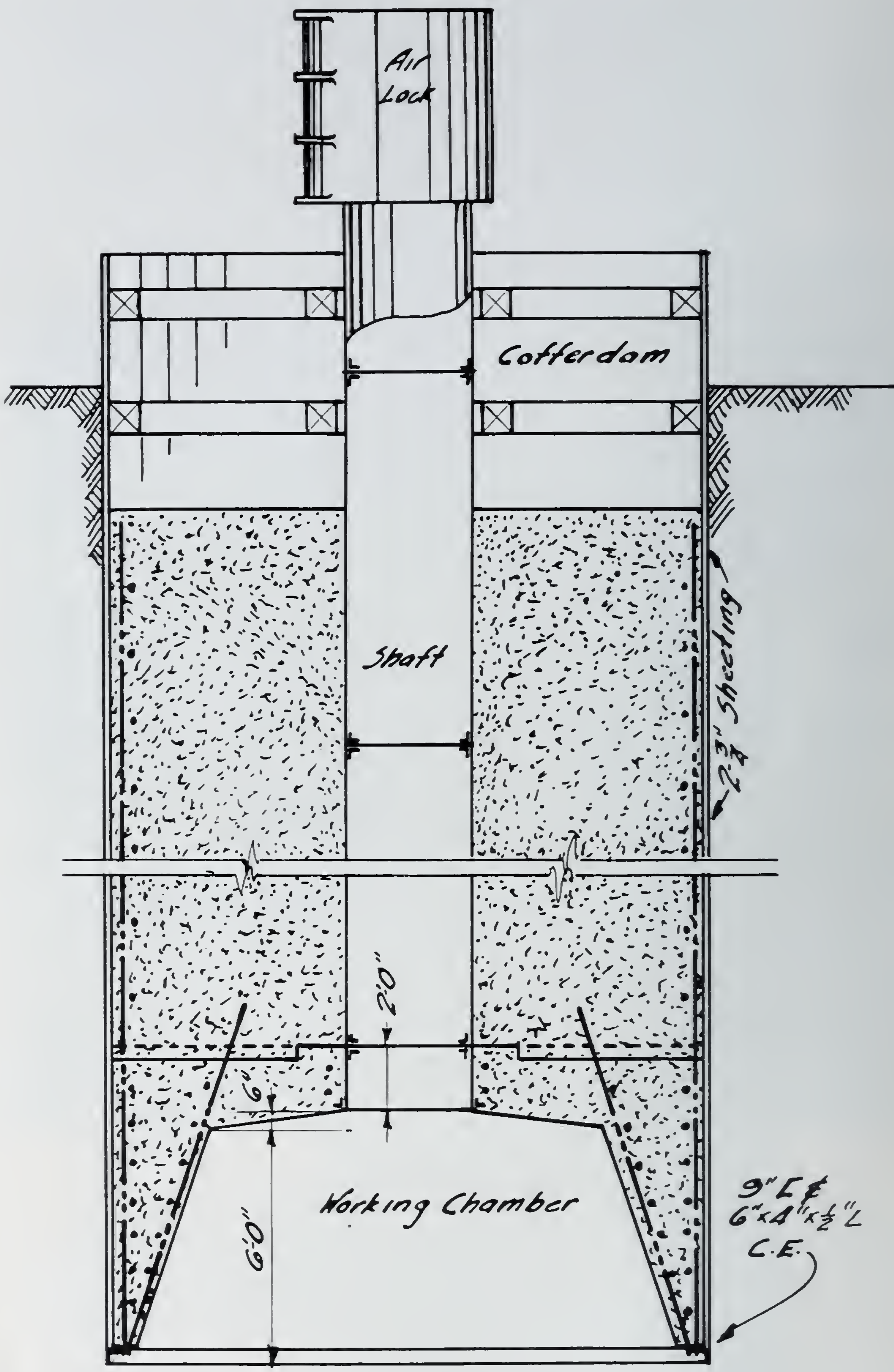

Fig. 12. Pneumatic Caisson.

out the water and permits men to work below water-level. In preventing the flow of water, the flow of material is also prevented, and the equilibrium of the soil is maintained.

This is the surest method of placing a foundation, and failures are very rare and are due only to poor workmanship or to accident.

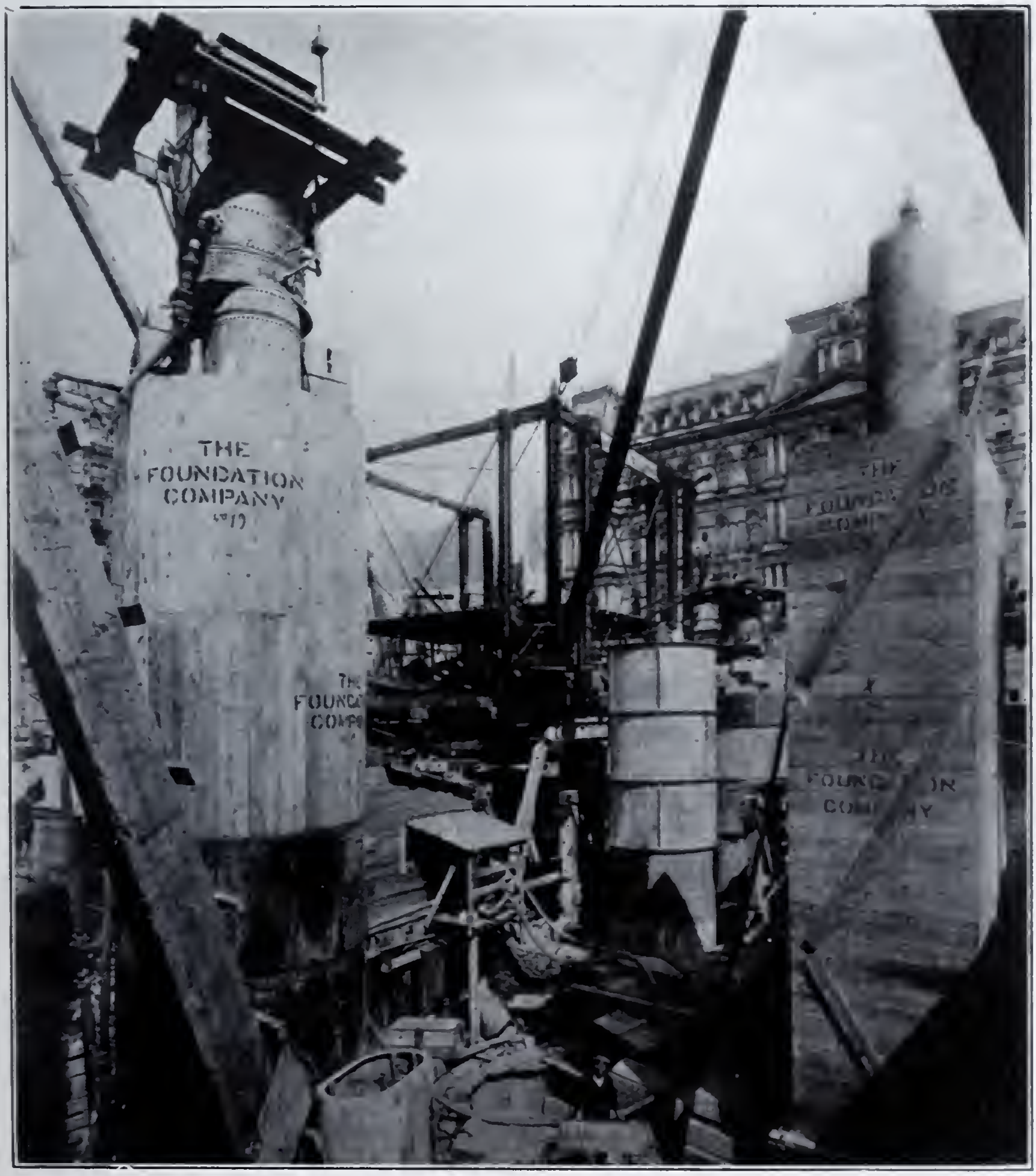

Fig. 13. Pneumatic Caissons in Foundation of Woolworth Building.

The most difficult kind of conditions have been overcome, and piers have been sunk to bed-rock alongside spread footings on top soil underlaid with quicksand without any appreciable settlement. The

ability to inspect and prepare the bearing surface is a great advantage, for this is the weakest point in a deep foundation. Pneumatic piers are limited in depth to about 100 feet below water-level, as the necessary air pressure beyond this depth is more than men can stand.

This type of foundation has been carried to its greatest development in building foundations in lower Manhattan, New York City. Here the demand for high and heavy buildings has necessitated that foundations be placed on bed-rock. The pneumatic caisson is the best solution of this problem and many of the higher buildings seen in the well known New York "sky-line" have foundations of this type. In some cases, pneumatic caissons are sunk to form a coffer-dam about the building site, after which the interior is excavated and the interior column footings placed in the open. Fig. 13 shows some of the caissons of the Woolworth building.

The economy of the open-method caisson and the surety of the pneumatic-method caisson have called into being a combined type. In this method, the caisson is sunk as far as is desirable by the method of dredging. Then an air deck is put in, the lower part of the caisson converted into an air-tight working chamber, and the excavation finished as in the case of a pneumatic caisson.

Each one of the types of foundation described has its particular field of utility and economy. It will always be found to be well worth the time spent in considering each in turn for the particular substructure under project, for rarely are two cases alike, and each foundation is a separate problem.

DISCUSSION

George R. Johnson: One type of pile that is not in use in Pittsburgh is the pipe pile. The Pittsburgh building code practically prohibits the use of that pile. It says that no type of pile shall carry a load exceeding 30 tons.

V. R. Covell, *Chairman*:* Suppose you describe that pipe pile in a little more detail.

*Chief Engineer, Bureau of Bridges, Department of Public Works of Allegheny County, Pittsburgh.

GEORGE R. JOHNSON: A pipe pile is nothing but an ordinary piece of well casing, say 16 inches in diameter and 3/8 inch thick. It is driven into the ground without any shoe on it and the interior material is blown out or jettied out to the depth of that length of pipe; then another piece is put on with an interior coupling and driven another 20 feet, or whatever the length of the pipe may be, and so on until you get down to rock. This type of pile is not at all new. I put one job down in 1906 and recently we uncovered some in New York that were put down in 1902, and we had a chance to observe not only the loads they had, but also their state of preservation. After they were cleaned out they were filled with concrete just like any ordinary pile.

V. R. COVELL: Would the durability of the pile depend pretty largely upon the nature of the surrounding soil?

GEORGE R. JOHNSON: I have heard that objection raised repeatedly, and I expected that it would be raised to-day. It is rather a difficult question. I have a piece of the pipe sunk in 1902 that shows a small amount of corrosion. If driven in cinders or places where there was acid it could not help but be corroded. We have not sunk any which have been uncovered lately, so I can not say. I know the ones we have put in are all carrying their loads.

C. W. LITTLER:* Mr. Johnson refers to a particular job of piling executed at the Aliquippa works of the Jones & Laughlin Steel Corporation at Woodlawn, and he, being aware that I happen to be familiar with this job, was cruel enough to request me to explain the details, which I will endeavor to do from memory. I did not come in here to lecture, neither is it my intention to advertise any particular piling construction, but, due to the interest which this particular piling job has created, I shall endeavor to describe the problem involved and how it was solved. For this excellent idea credit belongs to Mr. Mekeel, our Consulting Engineer, and not to me. The actual execution of the work was in the hands of the Foundation Company under our supervision.

*Chief Engineer, Jones & Laughlin Steel Corporation, Woodlawn, Pa.

A boiler house consisting of five 2000-horse-power boilers had to be built and supported by these foundations. A narrow strip of land, about 55 by 250 feet, was available. It is between one battery of operating rectangular coke-ovens and operating tracks, and within 30 feet of these the embankment sloped down into the Ohio River. The combined weight to be distributed over the various columns, carrying boilers and auxiliaries, as well as a stack 20 feet in diameter and 210 feet high resting on top of the building, was approximately 14,000 tons. This, in general, was the problem in determining the kind of foundation necessary.

The condition of the soil as verified by drillings showed a top layer of about 15 feet of cold slag fill. The next stratum was from 20 to 25 feet of yellow and gray clay, and below that was about 20 to 25 feet of sand and gravel. Hard rock was found to be about 65 feet below the surface.

Early this afternoon a question was raised with reference to reliabilities of test holes, as compared with the digging of wells, to examine the soil conditions. I wish to say that had we taken the result of examinations by means of test holes we would have been misled. Several wells were dug and we found that the stratum of yellow and gray clay was almost in the nature of quicksand, indicating that this section would give very little frictional resistance and would have to be confined; but the investigation showed conclusively that the load would have to be carried on piles instead of through concrete pads only.

Every known pile system was reviewed. Some designs would have necessitated the excavation of the entire hard slag top—a hole about 60 by 260 feet, and 20 feet in depth. This would have prevented operation of the coke-oven batteries as well as railroad operation unless sheet piling were driven all around, with great cost for shoring.

The essential elements which naturally had to be taken into consideration were the time of doing this job, and the cost. Furthermore, a construction which would give the boiler house either a floating foundation or a foundation resting on rock was naturally the controlling factor. All this led to the adoption of 16-inch standard welded tubes as piles driven to rock, each tube completely cleaned on the inside, refilled with concrete, and capable of carrying from 75 to

100 net tons per pile. We expected difficulties in driving this 16-inch casing through 20 feet of cold slag fill, and also in driving through the sand and gravel. Both fears proved entirely unwarranted.

Each pile of the 158 driven was composed of from three to four lengths of casing. After one section was driven, a collar forming the joint was inserted, and the next pipe put on top of that. No trouble whatever was encountered in driving to a depth of approximately 64 feet, perfectly vertical. The ordinary steam driver suspended from a locomotive crane was used to do this work. Talking about this standard casing, I consistently can mention that we tried to use second quality tubing, as it was immaterial whether the surface of such tubing was scratched or defective, but it was impossible to find any such second quality material, as the Jones & Laughlin Corporation makes only first quality tubing. Of the total of 10,000 lineal feet driven, not one single inch of lap-welded tube opened up.

Difficulty was also expected in blowing out these casings, especially through the cold slag, sand, and gravel. Compressed air at 100 pounds pressure was used. Material to be expelled from the casing was soaked and loosened with water. A three-inch pipe was inserted in the casing and worked down, after which the air was applied. In this way, material was expelled and thrown out 40 to 70 feet into the air. This operation was a remarkable performance and very interesting to witness. The piles, when cleaned, could be inspected to the bottom, and for such purpose an electric-light bulb was lowered. The next operation was to fill this casing with concrete. The cement used was very carefully analyzed and tested.

In comparing this total installation with other systems which we investigated, I will endeavor to give you a few figures which will illustrate the time and money saved. The excavation of 400 cubic yards may be compared with 30,000 necessary with another design. Concrete used for pads amounted to 450 cubic yards versus 2500 cubic yards, had we used another design of piling. For shoring about 12,000 feet of sheet piling would have had to be used, and this item we eliminated entirely. Three to four times as many piles would have been required in direct proportion to the load carried per pile.

The cost of this job was about two-thirds of that estimated for any other design, and possibly the saving is still greater, because the

comparison is made between actual cost and an estimate with other piling.

Since the adoption of this 16-inch casing for piling it seems that a great interest has arisen in this type of construction. Very little space is required to carry extensive loads. The steel casing of this type is standard, and thus easily obtainable, and it has been demonstrated that no difficulty whatever need be encountered in driving, cleaning, or filling. The complete job of excavating, piling, and concreting ready for the building took 45 days.

This type of pile construction seems to deserve very serious consideration, as it offers an opportunity to save time, money, and space, and is far more substantial than others. A great amount of theory is always involved in any kind of foundation work, and it seems that existing building codes are not in conformity with the progress of the times. We are all anxious to do a good engineering job and do not want any structure to fall down. Safety is at all times to be considered, but don't argue too much on theory and forget common-sense in any construction work. I might state that our problem was investigated very thoroughly, as an expenditure of $2,000,000 was involved.

C. S. Davis:* I wish to ask Mr. Johnson if he is familiar with the foundations that are under the addition to the Empire building? My recollection is that piles of this type were used.

George R. Johnson: I am sorry to say I do not know. That was not during my time and I have not been able to ascertain except from the Bureau of Building Inspection and they state that there was only 30 tons put on those piles.

V. R. Covell, *Chairman*: Can anyone answer Mr. Davis's question?

C. N. Haggart:† I made inquiry of the Bureau of Building Inspection. They told me it was less than 30 tons now, and will be only 30 tons when the building has been constructed 30 stories. I was surprised at that.

*Consulting Engineer, Pittsburgh.
†Consulting Engineer, Pittsburgh.

I have observed the conditions under some of the buildings constructed in Pittsburgh and it may be interesting to give here some of my observations. The Frick building is on rock. I assume the Carnegie building is also. This building here, the William Penn Hotel, is partly on rock, and the portion we are now over was constructed with "Chicago wells" down to rock. At the time this was being constructed I was engineer on the Davis Theater, then being constructed, and we drove test pits there down 20 or 30 feet and found gravel. We finally designed a foundation with the use of cast-in-place piles. In the Salvation Army building we had five test holes, one in each corner and one near the center and we found conditions uniform—mostly sand and a little gravel, and rock about 50 or 60 feet below the curb. We had some very unusual conditions. To keep our building up to the lot line and not construct party walls meant that we had to use cantilever footings to stay within our own lot. The auditorium columns made such heavy concentrated loads that we put these columns inside the wall line and had our loads concentric over the pile footings.

In the Gilmore building, right across the street, the same type of foundation was used, though I am not so sure about the use of the cantilever bases. I suppose they would be required. The Farmers Deposit National Bank building was put in when I first came to Pittsburgh. It has a very deep foundation and I believe there are about three basements underneath the first floor. If I am not mistaken they used spread footings, using steel grillage surrounded by concrete and cast-iron bases on top of that and steel columns on them. I am not sure about the wall columns, whether they ran those down to the level as interior columns or not.

I learned something recently about the Phipps Power building regarding its rather unusual construction. In that building a very thick wall, perhaps 28 inches thick, was built all around the lot. The building was 100 feet square. Steel columns were placed up on bases very much higher than the basement floor and a mat of four feet of concrete was placed over the whole of the basement. I presume that was done for the purpose of making the building so it would stand any water pressure in high water.

That is one of the difficulties engineers have in designing buildings for the lower part of Pittsburgh. I had a job some years ago

where the contractor had undertaken a contract to put up a building in Allegheny about four stories high and the architect had shown about six feet of concrete on the bottom of the basement. The specifications stipulated that it be reinforced against a 10-foot water pressure. The contractor came to me to make up a design. I started to figure out what resistance to upward pressure some of the interior columns would give and found that a 10-foot water pressure under a reinforced concrete floor would be almost impossible to hold down. Such a head of water would float the columns and shove them out through the roof, so we had to figure out something else. We finally compromised on considering that we would have only about half that head of water, and we put girders from one wall to the other and put interior columns on those girders. The contractor naturally lost money on his contract, due to discrepancies between architect's plans and specifications.

The Philadelphia building here is built on Gow piers. This type has not been discussed so far and I am not able to discuss it. We had a paper* before this Society on Gow piles which was very interesting, and I believe it is a very desirable piling for certain places.

I was interested in viewing the piles that were placed in Woodlawn. I saw something of the work and it was wonderful how they blew the material out of the pipe. I also saw some of that construction in New York City, where they use it very extensively. It is most unfortunate that the city ordinances here do not contemplate the use of that type of piling, for I believe it could be used with a considerable degree of economy in new construction, particularly where you have cantilever conditions and a concentration of loads near the walls and there possibly reducing the cantilever effect. The New York code allows you to figure 500 pounds per square inch of concrete and 7500 pounds on your steel, that being the relation of the moduli of elasticity of the two materials. There must be deducted 1/16 inch of the thickness of the metal in the pipe. The New York code also allows you to make one splice only. I noticed in one of the views Mr. Johnson had that he had three or four splices. I want to ask if they consider that good practice. I will say that I saw the piping at Woodlawn and I tried to observe whether it was straight. It looked perfectly straight to me, and all in very good condition.

*Proceedings, January 1925, v. 40, p. 339.

George R. Johnson: There is in New York an ordinance about one splice and I know of twenty-five or thirty jobs that have been put in. I do not like to say it, but I do not know of one of them that does not have more than one splice in it. If you have seen any New York work you will know that there is no place there where there is rock within 40 feet of the surface, and you have to have more than one splice in it. We have encountered engineers who have tried to reinforce that point. We have no patent on this, as far as that is concerned. Three or four or five other firms drive them. They all use cast-steel sleeves. My personal view is that that is the strongest part of the pipe, right where that steel sleeve is.

C. S. Davis: Would Mr. Johnson explain about the wood piles in the Navy Yard job; what was done to protect them from the teredo?

George R. Johnson: There was no provision to protect those. That was a dry-dock, all submerged and covered over with concrete. The action of the teredo is not so bad on that part of the Atlantic coast and the teredo has to have free water; it will not work under soil. In southern waters that is not true. At League Island the soil is within two feet of the top of the pile and a mat of concrete is placed over the tops of the piles, to ground level.

H. O. Hill:* There is an unusual type of foundation used on the North Side, Pittsburgh, for a gas-holder, which aroused considerable discussion regarding its adaptability to office buildings and similar construction. This foundation consists of a circular ring of interlocking sheet-steel piling 225 feet in diameter. These piles were driven about five feet into a thick bed of gravel located about 20 to 30 feet below the surface. The last pile was driven to lock into the first. On top of the entire ground surface was applied a concrete pad one foot thick. The gas holder was then constructed on top of this thin surface pad. The net result consisted of a cylinder with a clay piston, which serves as a very good foundation for a gas holder.

It was suggested at that time that smaller cylinders could be similarly constructed for supporting office buildings.

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H. A. THOMAS:* In this case, the radius of the cylinder appears to be very large in comparison with the thickness of the metal. Since the internal pressure which can be carried by a thin cylinder is equal to the unit stress in the metal, multiplied by the ratio of the radius of the cylinder to the thickness of the metal, it would seem that the effect of the steel in restraining the spreading of the earth within the cylinder would be comparatively small.

GEORGE R. JOHNSON: May I ask Mr. Davis, who has had much more experience than I, to say something.

REUBEN DAVIS:† Any discussion of foundations is nothing but an experience meeting. Mr. Johnson has given you an article on pipe piles, to which I would add our experience in their use. The question has been asked about the deterioration or rusting of the pipe shell. Recently we have uncovered a number of these pipes that have been in the ground for twenty years or more, and in none of them have we encountered any sign of decay or weakening from rust or otherwise.

The bearing power of piles has also been discussed. The New York building code allows 7500 pounds a square inch on the steel, deducting 1/16 of an inch for rust; and 500 pounds a square inch on the concrete. In other places 1000 pounds a square inch over the entire area is allowed. Some requirements are that a load not greater than one-half the satisfactory test load can be used. In Pittsburgh, I believe, the load is to be not more than 30 tons on any pile. A conservative load on a pipe pile would be a load that would not overly stress the concrete in case the entire shell went; that is, it would not exceed the ultimate compressive strength of the concrete. As the pipes are driven or jacked to refusal into solid bearing, an empty shell without concrete will easily stand 100 tons.

We have tested many of these piles where they have been used for underpinning buildings by the use of a 100-ton hydraulic jack. One of the first pipe-pile jobs in New York City was at 4 Wall Street, put in in 1904 or 1905. This building, I understand, is to be wrecked in the early part of 1927. All of these piles will be exposed. It seems that the average life of the modern structure,

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†Vice-President, The Foundation Co., New York.

according to recent discussion, is in the neighborhood of twenty-five or thirty years, which is about the length of time pipe piles have been used as a method of foundation.

As to the reliability of pipe-pile foundations, it is a matter of record that in no building in which they were used has there been any settlement.

One of the special advantages of this type of foundation is the time of installation, compared with that of sinking piers or caissons to solid bearing. The piles can be driven, cleaned, and filled with concrete very readily, thus saving materially in the time of construction, which in most buildings is a big item, due to carrying charges, loss of rental, etc.

RESULT OF GUNITE INCASEMENT ON STRUCTURAL STEEL*

By B. C. Collier†

One of the serious problems that has engaged the attention of engineers and chemists for the past several decades, or, in fact, during the entire period since the use of structural steel has become so extensive, has been that of protection against corrosion. Paints of all types have been tried with greater or less success, but even in those cases where a proper preservative coating has been found and used, there has still existed that other serious enemy of steel, fire; and to find a combination method of protecting against both has extended the problem.

For some time it has been a matter of universal knowledge that a coating of Portland cement affords the most positive protection against corrosion that can be obtained, but there arises the problem of proper application to secure the close contact of the cement to the surface and the subsequent protection of the coating. It has been assumed that concrete incasement offered this solution, but in 1917 Mr. E. E. R. Tratman, in the *Railway Maintenance Engineer*, November 1917, pointed out that the ordinary method of applying this protective cement coating defeated its own end, because, instead of placing the medium directly against the face of the steel, the result obtained is to entrain a film of air against the surface, leaving a void in which moisture settles and rusting continues under non-observable conditions. The effect of time has been to prove more fully the statements made by Mr. Tratman, and some rather startling testimony has been brought out recently. For example, Mr. A. R. Ellis, General Manager of the Pittsburgh Testing Laboratory, in an article in *Engineering News-Record*‡ says:

"The bases of many of the supporting columns and some of the bottom struts connecting them had been incased in concrete, probably at a later date than the original construction. This incasement, however, was not only ineffective, but defeated its own object, for the concrete was porous and absorbed

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†President, Cement Gun Co., Inc., Allentown, Pa.

‡Corrosion in an old viaduct at joints and in concrete-incased steel. Engineering News-Record, 1926, v. 96, p. 779.

water, holding it against the steel and actually promoting corrosion. Moreover the tops of many of the concrete caps at the columns were flat or even concave, allowing water to accumulate and lie against the steel, further promoting corrosion. At these points some of the columns were almost rusted through."

George W. Burke and P. B. Place in an article in *Concrete** say:

"To avoid such difficulties it is . . . suggested that concrete which is to be continuously exposed to moisture and large quantities of water be so designed that water cannot penetrate to and come in contact with the reinforcing and structural steel."

Mr. Tratman, in his paper, pointed out that the method of applying a protective coating with the machine known as the cement gun, which produces a concrete or mortar generally designated as gunite, eliminated the possibility of such air entrainment and made sure that the steel was intimately covered with a film or matrix of neat Portland cement. This coating, because of its being driven against the face of the steel at high velocity, fills every pore of the surface of the steel and eliminates any possibility of air pockets. A number of characteristic tests and reports have been made to prove this, but none more marked and extensive than was carried on in 1923 by the Engineering School of the University of Toronto. The report† of this work refers to accelerated tests, under the most adverse conditions, carried on during a period of more than a year, and the statement is made that under these extreme conditions, where unprotected steel showed very marked corrosion, the steel incased in gunite emerged with an absolutely clean and non-corroded surface.

The next problem before engineers was that of providing the second essential protection—that against fire. Concrete incasement of steel has been a very generally adopted practice for a number of years, because it has been supposed that while offering the protection against fire, it also offered the protection against corrosion referred to above. In view of such evidence as above recited, the latter protection seemed to be very doubtful, especially when members are subjected to damp,

*Corrosion of structural steel within concrete. Concrete, v. 29, August, 1926, p. 23.

†Gunite protection of steel structures, by Peter Gillespie and P. J. Culliton. Canadian Engineer, 1924. v. 47, p. 451-454, 472-476.

or gaseous or smoky conditions. As gunite had satisfied these conditions, the next problem was to prove the ability of gunite to withstand heat conditions. For this purpose tests on gunite were made at the Underwriters' Laboratories in Chicago, and at Columbia University fire testing laboratory, to determine its resistance to destruction by heat and water as well as the passage of heat. Tests were made on slabs and also on incased steel members, both of which were subjected to continuous temperatures of more than 1700 degrees F. for several hours, and also to the severe test of cooling with a stream of cold water while under this heat, and in no case was the gunite broken down.

It will be of interest to compare a report made by the Underwriters on a gunite slab 1½ inches thick with that of a report by the United States Bureau of Standards on a brick slab four inches thick, both subjected to temperatures of 1700 degrees. The requirements of these tests are that when the slab at any point on the unexposed face shows such heat transmission as to reach 300 degrees it shall no longer be considered as a fire retardant. In the case of the 1½-inch gunite slab, this elapsed period was one hour and 44 minutes, while the four-inch brick slab resisted the passage for only one hour and 26 minutes. It, therefore, is clearly established and generally accepted that a two-inch gunite incasement of main carrying members (columns and girders), and a 1½-inch incasement of beams, assures as positive a protection against destruction by fire as is possible to be obtained.

Having definitely shown the protection afforded against corrosion and fire by the use of gunite, the next step was to show to what extent the strength of the members was affected by the addition of this protection.

In 1923 the Dominion Bridge Company—feeling keenly the competition offered by reinforced concrete structures, due to the demands of engineers that the protective coating of concrete or gunite over structural steel should be considered as additional dead load—made a series of tests under the direction of Dean Mackay of McGill University, Professor Peter Gillespie of Toronto University, and Professor C. Leluau of the University of Montreal. Slabs were built, supported on beams and girders, and approximating as nearly as possible actual field conditions. In some of these slabs the beams were incased in concrete and haunched as is the usual practice. In others,

the beams were incased in a two-inch coating of gunite following, as is general practice, the alinement of the member. The tests showed a very marked increase in the strength of the total section; but, as the design was that of a T-beam section in both cases, it had been generally assumed that the increase was largely attributable to this form of section. As a matter of fact, a very exhaustive mathematical analysis and discussion by Dean Mackay before the American Institute of Steel Construction in 1925 particularly brought out this point.

Architects and engineers had admitted that the saving in dead load of gunite incasement over a standard concrete haunching would insure a very material reduction in the size of members, but they were not, in the face of such deductions as that of Dean Mackay, willing to admit any increase in the strength of the member itself, but insisted on penalizing the member to the extent of the weight of this incasement. It was, therefore, deemed advisable to carry on further tests to establish the extent to which such incasement might be considered to increase the strength of the member, and toward that end tests were made at the Engineering Experiment Station of Ohio State University in March 1926, under the direction of Professor Clyde T. Morris and Professor J. R. Shank.

For some years the problem of the maintenance of the carrying capacity of bridge beams and girders—or worse still, the ability of the members to withstand the constantly increasing traffic loads—has keenly interested highway and railway engineers, and for that reason, when it was determined to make these tests, it was decided to secure aid and co-operation of such men as Mr. J. R. Leonard, Bridge Engineer of the Pennsylvania Railroad, and Mr. H. T. Welty, Bridge Engineer of the New York Central and Hudson River Railroad. Mr. Leonard was so much interested that he immediately made arrangements to supply for this test members which had been condemned in bridges under his care. Four of these were built-up girders 24 inches deep, and the other four were 21-inch rolled iron beams. In addition, tests were made on two new 22-inch steel beams.

The old girders and beams were carefully cleaned and accurately calipered in order to determine the exact amount of deterioration, and it will be of interest to note that the reduction in flange section in some cases amounted to about 70 per cent. It was decided to test one of each of the three series without incasement in order to determine a

factor for comparison. The other new 22-inch beam was incased in two inches of gunite, reinforced with three-inch by three-inch by eight-gage wire fabric held in place with four ⅜-inch rods near the upper and lower flanges.

In each of the other two series, besides the bare members, one of the girders was coated with a standard two-inch coating, and the other two were reinforced by the addition of sufficient rods to restore the original steel area, and by the development of a reinforced gunite T-head section which would make the compression flange of equal value to the tension flange. This type of construction was developed, and patents have been applied for, by Mr. W. A. Fritz, of Columbus, Ohio. The advantage offered by this design is that of allowing the strength of the deteriorated member to be restored without removal from the structure.

The tests were made on a Riehle column-testing machine. The intention was to use a large new beam machine, but delay in installation prevented this, so that it was necessary to arrange the column machine by the addition of a heavy platform beam which would transmit the load direct. In this arrangement the loads were applied at the third points.

A very interesting development was that the bare members in each case failed by buckling of the upper flange. It is unofficially reported that tests made a few years ago by one of the larger steel companies conclusively proved that I-beams as designed and rolled contain an excess of steel in the tension flange, but that this excess is necessary in order to produce a properly balanced section, and in order to prevent the misplacement of the flanges. As the gunite incasement not only added this increased strength to the upper (compression) flange, but also added materially to the strength and stiffness of the web section, the results produced are not particularly surprising. For example, the new 22-inch I-beam showed a calculated value (assuming an elastic limit of 36,000 pounds) of 155,600 pounds, but actually failed at 140,850 pounds. A similar beam incased in two inches of standard reinforced gunite failed at 222,000 pounds—an increase of 43 per cent. over its calculated value, or 58 per cent. over its comparative tested value.

The comparative values on the old beams were even more interesting.

The old 21-inch beam tested bare failed at 84,300 pounds. Similarly, the old 21-inch beam incased with two inches of gunite reinforced only with mesh, and tested at seven days, failed at 166,900 pounds—an increase of practically 100 per cent. in value.

Another old 21-inch beam, reinforced with sufficient rods on the lower flange to make up the steel deficiency, tested at 28 days, failed at 227,950 pounds, or an increase in strength of 170 per cent.

The fourth old 21-inch beam, also reinforced to make up the steel deficiency, and also tested at 28 days, failed at 223,000 pounds, or an increase of 165 per cent.

The old 24-inch built-up girder tested bare failed at 146,875 pounds.

Another old 24-inch built-up girder incased in gunite, reinforced only with mesh, was tested at seven days, but due to failure of the machine supports at 170,000 pounds no comparative values could be established. With another of the old built-up 24-inch girders, reinforced with rods to make up the steel deficiency and tested at 28 days, a similar accident happened to the machine when the load had reached 252,400 pounds, or an increase of 70 per cent. above the comparative tested value of the old girder.

The final test was on another of the old 24-inch girders strengthened with rods for supplying the steel deficiency, and tested at 28 days. This girder failed at 327,960 pounds, or an increase in strength of 124 per cent. over its comparative value.

An analysis of these figures seems to prove conclusively that with all due regard to conservatism it will be safe to assume an increase of 25 per cent. in strength of beams incased in two inches of gunite reinforced with mesh. With such an increased value, let us illustrate the saving that will accrue in the design of a building when taking into consideration both the decrease in dead load and the increase in strength.

Assume a cold-storage building, such as described in an article in the *American Architect* of June 3, 1925,* which was built in The Bronx, New York City, where the spans were 20 feet and the designed live load was 500 pounds, with five-foot spacing between beams for a concrete flat slab, five inches thick. The total uniformly distributed load per foot of beam is therefore 2500 plus 280, plus 300, or 3080 pounds, which would require an 18-inch, 70-pound beam. If

*V. 127, p. 515.

we substitute gunite incasement, the load would be 2500 plus 140, plus 300, or 2940 pounds, or the use of an 18-inch, 65-pound beam. If, in addition, we consider that the strength of the member can be considered as having been increased to such an extent as to allow the use of 20,000 pounds fiber stress, the member can be still further reduced to a 55-pound beam.

Without giving consideration to the similar decrease in the size of the supporting girders, or of the columns, it will at once be seen that the saving in steel in the beams of one panel only would be five beams, 20 feet long at 15 pounds per foot, or 1500 pounds. This, at five cents, would amount to $75, and as there were 700 such panels in this structure, this saving would be $52,500.

Of interest also in this particular building was the reduction in the area of the footings, which were very difficult to build, due to bad conditions. With the information now determined by the tests at Ohio State University it would have been possible to effect still further reduction and economies over those obtained purely from the reduction in dead load.

In addition to the economies that can now be gained in new construction by taking advantage of the information afforded by these tests, perhaps greater savings can be effected by the use of the method of strengthening that was developed through these tests. Already a number of railroads have begun investigations toward the strengthening of existing structures that are too light for modern traffic. One railroad has had plans made to determine what work should be done to increase the strength of plate-girder bridges designed for Cooper E 30 specifications in order to comply with E 65 specifications. Other railroads have structures in which members have suffered serious deterioration due to the action of gases and smoke and which, if removed, would involve not only a large expenditure, but also very serious inconvenience both to the railroads and to the public, and they are already giving consideration to the use of this method of restoration.

In planning such restoration, either in buildings, or in railroad or highway bridges, care must be taken to see that the vibration in the structure is reduced to a minimum while the gunite is being applied, because naturally such repairs, where success is dependent on obtaining a thoroughly composite condition, require careful workmanship, as well as proper design.

In view, therefore, of the continuous demand of architects and engineers for structures that will measure up to the standards of (1) rapidity of construction; (2) positive assurance against failure; (3) fire resistance; (4) permanency; and (5) economy, it would seem that the most careful consideration should be given to the various experiences and tests herein cited, as proving that structural steel incased in gunite fulfills these conditions.

DISCUSSION

J. R. SHANK:* I did not understand exactly the part I was to play in this discussion when Mr. Collier asked me if I would be present. I have no paper worked up and I will ask you to bear with me if I occasionally take a little time to look at my notes to pick out the results of the tests about which I intend to speak. I want first to bring out some points that Mr. Collier did not bring out in his paper. These tests were not originated by either Professor Morris or myself. Mr. Cooke, of the Fritz-Rumer-Cooke Company, Columbus, inquired of us if there were any facilities available for making such tests. He said he had contemplated the idea of loading pig-iron on these beams, and when he began to compute the amount of pig-iron that would be required it began to appear that he would still be piling pig-iron if he had adopted that method. We had just got in a column-testing machine for testing up to 500,000 pounds and were expecting two others of slightly different types, one for 1,000,000 and another for 400,000 pounds, especially adapted to beam work. We told him we could handle these tests very nicely on the 400,000-pound machine; but the machine did not come in time, and we were obliged to adjust our column machine for this service. I found afterwards in operating the new machine that there were some things in favor of the adjustment we made.

These tests at this time have been written out only in a preliminary draft. We have not gone any further than that. As I have neither charts nor slides, it may be somewhat difficult for you to follow me; however, I shall try to arrange the numbers of these beams so that you can catch on as I go along.

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I want to make a slight correction in Mr. Collier's statement as to the depths of the steel. The built-up stringers were 21 inches deep and the I-beams were 24 inches deep. The 21-inch stringers came from Chicago and the I-beams came from Allegheny—all furnished by the Pennsylvania Railroad through the courtesy of Mr. J. F. Leonard.

At the present time the Engineering Experiment Station of Ohio State University has used up all of its funds and no more can be available before July 1, 1927. It is the purpose of Professor Morris and myself to publish a complete report of this work as a bulletin of the Engineering Experiment Station just as soon as possible after July 1, 1927. Copies may be had directly from the office of the Director at Columbus as soon as the bulletin returns from the press, but I will ask you to withhold final judgment until this bulletin is out.

The stringers are marked with the Roman numerals XI, XII, XIII, XIV, and XV. The I-beams are XV, XVI, XVII, and XVIII. The new beams were 22-inch Bethlehem I-beams and are referred to as A and B. I will read over what was done to these various beams from a letter sent out as an invitation by the Fritz-Rumer-Cooke Company to engineers throughout the country who might be interested in viewing the tests.

Stringer XII was tested bare. Stringer XIII was incased with two inches of gunite only and tested at seven days. No. XIV was built up supposedly to restore it to its original value when it was new, and tested at 28 days. No. XI was of the same nature as No. XIV, but there was a special arrangement made with the reinforcing steel added with reference to improving it by way of web or shear reinforcing, as you ordinarily understand it, for concrete beams. We more or less paralleled that same work in the case of the I-beams. I-beam XV was tested bare, just as it was, in the corroded condition. No. XVI was incased in two inches of gunite only and tested at seven days. No. XVII was built up to restore it to its original condition and tested at seven days. No. XVIII was the same, but tested at 28 days.

The loads were concentrated loads applied with the primary idea of following up the tests with strain-gage measurements of the top and bottom to find out how the tension and compression flanges were

affected, and whether the bond would be maintained between the steel and the concrete throughout the test, and if it broke we could determine by our strain-gage and deflection-gage measurements just when that occurred. In not a single one of the tests was there any evidence in the results to indicate that the bond failed even up to the final break. The bond held all the way through with the exception possibly of the extreme ends beyond the loading points. In one or two cases we did notice a slight crack or opening between the concrete and the steel as it projected out beyond the concrete at the end, but we did not find anything anywhere on the curves representing the strain-gage readings either on the bottom flange or the top flange or in the deflection to indicate that the two beams—the steel I-beam and the reinforced concrete beam—were acting separately. We measured the deflections by stretching a fine steel wire along the neutral axis from support to support, and we fastened a mirror with a scale on it on the I-beam itself and made our readings directly. We were able to read accurately to 1/100 inch and sometimes to 1/200 inch by the eye. The strain-gage measurements were made by the 20-inch Berry strain gage in the hands of the speaker.

As the report was written up, there was not very much space devoted to ultimate loads. All the discussion was made on the strain-gage records as to the behavior of the beam, and that in the region of working loads. I would like to pass around to you sketches of the calibration data for the I-beams and stringers. They are marked with the numbers I have read out to you. We used Mr. Leonard's calibration data as well as his calculated section moduli and the moments of inertia from those corroded beams.

V. R. COVELL, *Chairman*:* It might be worth while to explain how the steel section was restored.

J. R. SHANK: The steel section was restored by building a reinforced concrete (gunite) beam around the steel. We added steel bars, in some cases just above the flanges of the steel beam and in some cases below, in different arrangements. The designs of these were worked out by Mr. Walter Braun, Consulting Engineer, of Columbus. They were built up by the Fritz-Rumer-Cooke Com-

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pany, and we tested them just as they were given to us. The compression flange was built up by building out a T-head wider than the original steel flange, following his computation entirely. I made recomputations on Mr. Braun's designs as accurately as I could, making an assumption of the ratio of the moduli of elasticity, and I have comparative data on just how near the final test came to the calculation I made. The calculation I made indicated in general a higher strength than Mr. Braun's calculations.

I might mention here that the Fritz-Rumer-Cooke Company, being concerned about the bond of the gunite on two sides of the steel, cut three or four holes in the web about eight inches in diameter so the gunite would be carried right straight through the web, hoping thus to bond one side to the other more effectively. Also, some of the reinforcing bars put on the bottom were turned over and welded at the end through a hole burned in the flange of the stringer or the web of the I-beam. In case of No. XI, the one that had the special arrangement for shear reinforcing, we found no difference, and, as a result of strain-gage measurements, it did not appear that the welding was any improvement. The materials worked together.

In preparing for a test, we carefully bedded bearings and reactions on the test specimen in a half-and-half mixture of Portland cement and plaster of Paris which, as far as possible, we allowed to stand from the day before. The loads for the corroded stringers and the I-beams in all cases were applied directly to the steel and not to the concrete. In all cases for the corroded I-beams and stringers the gunite did not run above the top line of the steel, which resulted from an attempt to get the conditions you would get in applying gunite to a floor under a highway bridge over a railroad. You can cover it only up to the top; you can not cover the top flange. I have made up a number of comparative curves. I have comparisons of the test beams with the theoretical bare beams based on Mr. Leonard's calibration data. The corroded beam that was tested bare showed a slightly better indication than the theoretical computations for that same beam. This is not at all surprising, because a man calipering a corroded beam will naturally pick out points that will be pretty well corroded, so his measurements will be usually slightly on the safe side. The plate girders No. XI, XII, XIII, and XIV were of material rolled prior to 1885 and were probably wrought-iron. We determined the

modulus of elasticity, by measurements, to be about 28,000,000, and we based the curves on that. The curves indicated that the new steel beams had a modulus of elasticity close to 30,000,000, and we did not make any tests of them or of the Bethlehem I-beams, as they were rolled at a much later date. We have here a comparison of the stringers No. XI, XII, XIII, and XIV. Compared to the bare beam at 14,000 pounds per square inch, outer compressive fiber stress, beam No. XI was carrying about 35,000 pounds total load over the theoretical bare beam. Beam No. XI ran highest. On the tension side this excess was 29,000 pounds. Beam No. XI was supposed to be brought up to the original. Steel bars were added to No. XI and the T-head was built out. No. XIV was of the same type, and tested just a little bit below on the compression side and a little below on the tension. The excess for No. XIII, the seven-day test, was just about half as great as No. XIV. The bare beam was running about 5000 pounds over the theoretical.

The 24-inch I-beams in most cases ran still better than the stringers. The bare stringer that was used was one of the best of the lot. At 15,000 pounds per square inch the best of those stringers (No. XVII, the seven-day test, which was built up to bring it back to the original condition) carried about 74,000 pounds more on the compression side and 79,000 pounds more on the tension side. No. XVIII was 62,000 pounds and 75,000 pounds, respectively. No. XVI, incased two inches only with gunite and no extra steel, in a seven-day test, ran over 30,000 and 33,000 pounds, respectively. The bare beam carried in this case about 15,000 pounds over the theoretical. The top and the bottom carried about the same excess.

Here is something a little more interesting—the comparison made with the original new beam. Mr. Leonard supplied us with data as to the make-up of the original new stringers. The I-beams used were standard and we were able to get published data. Here is a comparison of the beams as tested with the theoretical new beams. Beam No. XI, at a load of 14,000 pounds per square inch, carried about 23,000 pounds more than the computations would indicate for the original new uncorroded stringer, indicating that Mr. Braun had figured safely on the extra that he designed for adding to that corroded steel beam to bring it back to its original value. On the tension side the excess was only 10,000 pounds. Beam No. XIV showed an

excess of 21,000 pounds on the compression side and 21,000 pounds on the tension over its new theoretical values. Beam No. XIII, incased only, no extra steel added, carried the same load as the theoretical new beam as indicated for 14,000 pounds per square inch in compression, and at 21,000 pounds per square inch it dropped 4000 pounds below. On the tension side, beam No. XIII carried 2000 pounds less at 14,000 pounds per square inch, and 10,000 pounds less at 21,000 pounds per square inch. Beam No. XIV, the other reinforced incased stringer, at 14,000 pounds per square inch showed an excess load of 20,000 pounds for the compression side, and 21,000 pounds excess for the tension side. At 21,000 pounds per square inch these excesses were 28,000 pounds and 23,000 pounds, respectively. It may be well to note here that the bare beam tested showed reductions of loads carried at 10,000 pounds per square inch for compression of 6000 pounds, and for tension also. For 21,000 pounds per square inch these were 15,000 pounds each.

Similar observations on the I-beams show still more striking results. I-beam No. XVIII, a reinforced, incased I-beam, tested at 28 days, showed an excess at 15,000 pounds per square inch in compression of 20,000 pounds, and in tension 23,000 pounds. At 22,500 pounds per square inch these excesses were 30,000 and 23,000 pounds, respectively. I-beam No. XVII showed excesses of 31,000 and 16,000 pounds, respectively, at 15,000 pounds per square inch, and 36,000 and 17,000 pounds, respectively, at 22,500 pounds per square inch. The simple incased I-beam No. XVI, tested at seven days, showed reductions that were little less than those of the bare beam tested. The bare beam showed reductions of 25,000 and 40,000 pounds, respectively, at 15,000 pounds per square inch, and 43,000 and 66,000 pounds, respectively, at 22,500 pounds per square inch. Similar results for the simple incased I-beam No. XVI are 21,000, 37,000, 33,000, and 60,000 pounds, respectively.

It will be noticed that in many cases the beam tested at seven days showed results in excess of the 28-day beams and in others less. There does not seem to be any evidence that the 28-day beam was any stronger. This is not totally without reason, for gunite being rich, dense, and dry of mixture should set up early. Furthermore, the beams were not kept damp after the first week; the thickness was rather slight and it would all dry out rather early.

We have similar data for the two new 22-inch Bethlehem I-beams, one incased in gunite and another incased in poured concrete. I will not trouble you with more figures on this. There is nothing greatly different from what I have already indicated for the corroded sections.

In addition to these tests, the first series of the tests already outlined, Professor Morris thought that more data ought to be obtained along this line with a view to the effect of the incasement of beams and columns in new structures. We accordingly made a number of tests on columns. Our machine has a capacity of 500,000 pounds. First we wanted to get eight-inch columns, but they were not easily available. Instead we used six-inch H-columns, 18 feet, 10 inches long. Three of these we incased in cement-gun concrete and three in poured concrete. The six-inch H-columns were built out to 10 by 10 inches with cement-gun concrete, and the same was done for the poured concrete columns. We tested a bare column as a basis for comparison. For the poured concrete columns we made up a mixture of 2000 pounds of concrete, using the water-ratio method, but without preliminary trials. We obtained 2500 pounds of concrete instead of 2000 pounds. The mix was about 1-2-½-3, using ¾-inch gravel, making it to a consistency of about seven or eight inches slump. The mesh was wrapped around these columns square. We had no room for puddling bars and had to rely upon wrapping the forms instead. The tests of these columns were made with flat ends on the testing machine, top and bottom, no ball joint whatever, and we tested them as they were poured without moving them far out of their vertical position.

The unincased column tested failed at a unit stress of 31,000 pounds per square inch. The allowable unit stress would figure around 5000 to 6000 pounds per square inch according to formulæ used by the Bethlehem Steel Company for columns of that length. It stayed straight all through the test until toward the end and then started to bow at right angles to the web, and finished up with the ends still square with points of counter flexure about two or three inches from each end. We tested all six columns in exactly the same manner, taking strain-gage measurements on the four corners of the steel, and none whatever on the concrete. The load was applied on the steel only. The concrete was about one inch short of the end of

the column. In all six tests (cement-gun and poured concrete) we were unable to get a column failure.

C. N. HAGGART:* Was that unusual stress shown by the strain gage?

J. R. SHANK: That was from the average of the strain-gage measurements for the steel at the center of the column. The stress calculated from the strain-gage measurements at the end of the test was 31,000 pounds per square inch, which was at the failing point of the column.

V. R. COVELL, *Chairman*: That was 31,000 pounds to the square inch?

J. R. SHANK: That was on the bare steel. Thirty-one thousand pounds per square inch was on the bare steel column tested. It resulted from either the strain-gage measurements or directly by dividing the maximum load attained, by the cross-section. There is a slight discrepancy between the two. The total mean maximum load, 180,000 pounds, divided by 5.81 (square inches), gives 31,000 pounds per square inch; whereas the average strain-gage difference (107 units) times the value in inches of one strain-gage difference, or 0.00000944 times 30,000,000, gives 30,300 pounds per square inch.

C. N. HAGGART: Was that the maximum stress?

J. R. SHANK: That was the maximum unit stress before the beam started to buckle.

C. N. HAGGART: According to the book, only 5000 pounds would be allowed over the whole section. Was that 31,000 over the whole section or only a part of it?

J. R. SHANK: I took strain-gage measurements, the average of which would be 30,000 pounds per square inch.

C. N. HAGGART: Thirty-one thousand multiplied by the cross-section would give you the total load?

*Consulting Engineer, Pittsburgh.

J. R. Shank: Where it started to buckle I could not get any more load. That was the greatest strain-gage measurement I got on that steel; also the maximum total load. I continued to take strain-gage measurements throughout the test with increments of the load, and the largest I got was just before it started to fail. After that, one side ran away from the other and the strain gage did not mean anything.

F. M. McCullough:* I suppose the average of the strain-gage measurements checked the average stress obtained by dividing the load by the area?

J. R. Shank: Yes, they were the same.

C. N. Haggart: The strain-gage measurements at the four corners were not always the same?

J. R. Shank: No, there was a certain amount of weave back and forth.

F. M. McCullough: What you have is the average?

J. R. Shank: Yes, the average. I read the incased column the same way, at the four corners, and that meant that I had to cut into the gunite to get to the corner of the steel. Then I had to cut part of each corner off because the strain gage had a neck only 1½ inches long, so in that way I was able to get the stress on the steel. I had the total loadings as indicated by the total measurement from the testing machines, from which I could find out how much was taken by the steel and how much by the casing, the strain-gage measurements determining the load on the steel. For comparison with A and B, the tests made on the new 22-inch Bethlehem I-beams, we attempted to pour a beam incasement on another Bethlehem 22-inch I-beam covering the steel at all points two inches above and below and to the side of the flange. This made a rectangular section. I puddled and superintended the pouring of this myself, because I wanted to get results without honeycombing, but I did not succeed in making a good job of it.

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I have heard other engineers say they could. I could not get it up and against the bottom side of the top flange nor completely fill under the bottom. The mesh was three inches square both ways and with the ¾-inch gravel used it had a tendency to arch right at the flange above which was one of the horizontal wires. The tests showed up very well in spite of honeycombing, though at the end of the test there was an evident horizontal shear failure right along the top flange on account of that weakness.

Not being exactly satisfied with one test on a bare H-column on account of the high strength shown, I decided to take one of the gunite-incased columns, take off all the gunite, and put it in the testing machine, as a bare-column test.

R. P. Forsberg:* Was it not rather difficult to knock off the gunite?

J. R. Shank: It was. It was much more difficult than with the poured concrete. Putting a chisel under it only broke off small pieces at a time.

W. I. Parry:† What increase did you get over the plain-edge column?

J. R. Shank: I have here the curves of one of the columns. I have the average of the three gunite-incased columns and we will consider loads at 15,000 pounds per square inch. The bare column took about 89,000 pounds at this unit stress. The gunite-incased column averaged about 152,000 pounds. The poured concrete was better. At 15,000 pounds it carried as an average of about 178,000 pounds.

G. C. Ramsdell:‡ I would like to ask Mr. Collier what effect, if any, the excessive vibration on highway and railroad bridges would have on the gunite incasement. By this I mean a new steel structure which has been coated with gunite. The reason I raised this question was for the purpose of getting information in connection with the

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†Engineer Salesman, Carnegie Steel Co., Pittsburgh.
‡Engineer, The Travelers, Pittsburgh.

first structure of this kind, to my knowledge, in the East, which was erected I think some four years ago over the Quinnipiac River at New Haven, Conn., by the C. W. Blakeley Company, contractors of that city. At that time the question arose whether the excessive vibration on this bridge would not crack the gunite covering and cause it to chip or flake off, in the same manner that concrete has done on similar structures.

B. C. Collier: Vibration has an injurious effect if the gunite should be applied while the bridge is under high vibration. The tests described in the writer's paper and referred to by Professor Shank were started due to the necessity of replacing a portion of one of the stations along the line of the Pennsylvania Railroad. The structures over the railroad had cost in the neighborhood of $1,500,000 and are in a very serious condition. To rebuild these structures would mean an expenditure of considerably more than the original cost and would also mean a condition which would seriously discommode thousands of people daily. It was, therefore, sought to prove by these tests that through this method of repair it is possible to strengthen and maintain that particular structure, and that it could be done at a very great reduction in cost and without very much inconvenience.

In the preliminary discussion of the project, the first question asked the writer was whether or not it was possible to do this work and be sure of obtaining any positive results while the structure was under such constant vibration. My recommendations were that it will be necessary to relieve one-half of the structure from the traffic while the beams and girders are being strengthened, and, at the same time, so regulate the traffic on the other half of the structure that it would pass slowly and thus reduce vibration. I believe that these tests have shown that within a period of one week after the gunite has been placed it will be possible, without danger, to change the flow of traffic to the finished half, and that the condition would then be thoroughly safe. Attention is particularly called to the fact that these test girders, one week old, were handled with considerable roughness in being placed in the testing machines.

G. C. Ramsdell: In connection with the gunite treatment of sheet piling and piling for footings of buildings, I was told of a case

in connection with sheet piling some six years ago in Ohio where for some reason the gunite failed to stick.

B. C. Collier: I can not understand why they should not be successful in the use of gunite as a protection for a pile, especially if the reference was to wooden piling. It is rather general practice in the country at the present time to cover wooden piles with gunite and subsequently drive them. Perhaps the most outstanding illustration is that of the Port of Tacoma, where wooden piles have been very rapidly destroyed by the teredo and other marine borers, and where also concrete piles have shown the usual injurious effects of salt-water action. When the Chief Engineer of the Port of Tacoma was making investigations as to the most desirable type of construction, he had before him the serious trouble that had been experienced in San Francisco, as a result of which in a period of only about three years approximately $25,000,000 worth of piers were almost entirely destroyed through teredo action. It seems that the conditions in San Francisco Bay were rather peculiar in that for years the salt water of the upper portion of the bay was highly diluted with the fresh water from the San Joaquin and Sacramento rivers. In 1917 or 1918, not only did they experience two years of severe drought, but an extraordinary call on the water for irrigation purposes, with the result that it was found that the teredo had extended its operations as far as 30 miles up the river, with the result that pier after pier was destroyed. Immediately an investigation was started not only of the timber structures, but also of the concrete structures, and the report made by the committee indicates that after about seven years the concrete piles also show similarly rapid destruction.

As a result of this the Chief Engineer of the Port of Tacoma, who had known of work done in protecting wooden piles with gunite in San Juan, Porto Rico, in 1913, had an investigation made not only of the gunite-treated piles, but also of concrete piles and creosoted piles in adjacent piers. In his report the investigating engineer summarized by saying, "Based on this examination I unquestionably recommend the use of gunite-coated piles."

Mr. Osgood, however, was still not satisfied and had a number of piles made for testing purposes. Some of these he drove and pulled as often as four times, with the final result that gunite-coated piles

were specified for the piers, and within the last six weeks the writer has had the pleasure of receiving a letter from Mr. Osgood in which he said, "You will be pleased to learn that I have had a diver examine all of the fifteen hundred piles in the pier and we find no indication of any deterioration of any type."

The answer to Mr. Ramsdell's questions therefore is that these piles which were driven after being coated have shown no indication of breaking down, although they have now been subjected to very severe conditions for a period of six years.

There are records of gunite construction subjected to continuous vibration now over a period of a great many years. Perhaps one of the most interesting cases is that of the bridge on the Nickel Plate Railroad at Seventy-ninth Street, Chicago. Another case is that of the street crossing immediately adjacent to the station at Columbus, Ohio. These were treated in 1914 and are subjected to extremely high vibration from traffic above, as well as from trains passing below. A similar case is that of the bridge at Calvert Street, Baltimore, immediately adjacent to the Pennsylvania Railroad. The gunite work was done on this structure in 1912 or 1913 and there has never been any indication of any of the material being shaken off.

J. R. Shank: One other thing I want to mention. This column test gave a fairly good indication of the modulus of elasticity of the material, and I found that the modulus of elasticity of the poured concrete was considerably higher than the gunite concrete, notwithstanding the fact that the gunite concrete was stronger, without much question. We attempted to make some tests of the gunite that was used in these beams. It was not very successful. The small mold we used, four by four inches, was too small to get a first-class concrete, but I got some that ran as high as 4000 pounds per square inch. Other samples were lower, but they failed as the result of the laminations on account of working with forms so close together. In general, from the appearance of the concrete it was 4000-pound concrete, yet my test showed that the modulus of elasticity of that concrete was lower than the poured concrete.

Apparently gunite will stand vibration better, because, in attempting to clean these beams, I used a sledge hammer on the steel and it did not do any good. It would not loosen the gunite from the

steel. It had to be cut off. With the poured concrete you could get it off by rapping the steel. I have been running a few observations on the time flow of concrete and, therefore, expecting some in this work, I accordingly, at a fairly high load, held the load for half an hour to see how much the beam would drop, expecting the concrete to readjust itself somewhat in that time. I got a very slight effect. In the course of days, weeks and years, however, this may make considerable difference and will serve to throw more load back onto the structural steel, as occurs in ordinary reinforced concrete columns.

W. I. Parry: Just a question in regard to these tests. On the tension side of the girder beam, how can the gunite and steel act in unison when they do not have the same elastic limit. You design a concrete girder and your neutral axis is one-third from the tension side. The concrete is taking care of compression as you supply tension in one-third of the concrete in the design. Now you start in with gunite and add two inches to the tension side. Theoretically, how could the steel and the concrete act together in tension when they are totally different?

J. R. Shank: They will act in tension up to the point where the concrete cracks. After that the steel must take it all.

W. I. Parry: That being the case, how would you with transverse load increase the capacity of a girder by adding gunite to its lower flange?

J. R. Shank: You can not improve it very much. These tests indicate that they are not improved to any great extent. Also a certain amount of that concrete up near the neutral axis will be working in tension. Tests on reinforced concrete beams usually show well on the safe side of the ordinary theoretical procedure.

B. C. Collier: In Professor Shank's report, I have not been able to understand the reference to the modulus of elasticity. I do not question his report in any way, but simply call your attention to this, because all of you gentlemen will understand how the modulus of elasticity would affect his report and can probably explain it better

than I. I do desire to say, however, that the tests made by the United States Shipping Board in 1918 showed the modulus of elasticity to be about 5,000,000. However, the calculations made by Lehigh University and Mr. George E. Strehan of New York City based on later tests were premised on the value of $N = 10$, so as not to vary from the recommendations of the Joint Committee.

P. W. PRICE:* One point brought out by Mr. Collier may have something to do with this. I understood that in testing I-beams you find that the tension flange is relatively stronger than the compression flange. In other words, in testing bare I-beams the failure is more likely to occur in the top flange than in the bottom. Therefore, if you incase your I-beam in gunite you are increasing the strength of the compression flange where the increased strength is generally most needed. The gunite will, therefore, assist in developing increased strength in the compression flange, while in the tension flange it acts only as protection from corrosion because it can not be counted on for taking tension. If I got your point correctly, is not the above a good way of stating one of the advantages of gunite for use either on new beams or to increase the strength of old ones?

J. R. SHANK: Of course the bottom of the concrete beam is carrying no working load in tension.

P. W. PRICE: Then reinforced concrete beams are no good?

J. R. SHANK: When your steel gets to 16,000 pounds to the square inch at the bottom of the beam when the ratio of the modulus of elasticity is 15, the concrete at the tension steel will have to run over 1000 pounds per square inch. No concrete will stand that, and the tests showed cracks.

V. R. COVELL: Does no damage result from those cracks?

J. R. SHANK: No. Tests have even shown that the crack is so small that it does not let in water or gas to corrode the steel.

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ROBINS FLEMING:* We are told that with continuous welded connections for beams we gain 25 per cent.; if we use J. & L. "Junior" beams we gain another 25 per cent.; and if we use gunite we gain another 25 per cent. If Professor Young, who has been quoted, were here he would tell us that if we figured our beams as we should where there is a T-shape reinforced concrete slab, we would gain 25 per cent., and Mr. Miller tells us that if we use the specifications of the American Institute for Steel Construction we gain 12 per cent., making a total gain of 112 per cent. If we have all these gains, including the gunite, do we need any steel beam at all? Of course, the percentages quoted are exaggerated, but the principle is the same.

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DESIGNING STEEL STRUCTURES FOR ARC-WELDED CONNECTIONS*

By A. M. Candy†

For a number of years the welding engineers of the Westinghouse Electric & Manufacturing Company have realized that arc welding could be used advantageously for making connections between steel members used in various structures such as buildings. Numerous tests which have been conducted in the past, the results of which have been published, show that properly designed and executed arc-welded connections will stand up under alternating stresses and vibrating loads beyond the point of failure of the members joined.

To convince the general public that these statements are true, it was determined to make up a series of test specimens, using members of appreciable size such as are actually used in building construction and assemble them in various groupings to bring out as fully as possible the decided advantages which are made available through the use of arc-welded connections instead of riveted connections. In lining up this series of tests a number of facts were to be substantiated.

1. Continuity of beams through columns can be secured at reasonable cost.

2. Absolute fixation of beams to columns, etc., is secured by the arc-welded connection.

3. Arc-welded connections which are economical of production will result in joints which will remain intact up to the ultimate rupture of the members joined.

4. Saving in material, due to elimination of fittings, and better distribution of metal in the sections can be obtained.

To substantiate these ideas three test specimens were built as illustrated by Fig. 1, which shows specimens 2, 4, and 3, respectively (from left to right), above specimen 20. Each specimen comprises an H-column eight inches deep, two feet high, weighing 32 pounds per foot; and two cantilever Bethlehem I-beams nine inches deep,

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three feet long, weighing 20.5 pounds per foot. The detail connections for the specimen are as follows:

Specimen 2 was constructed by welding two seat angles (4 by 3 inches by 3/8 inch, and 6½ inches long) across the faces of the column with the four-inch legs outstanding. Only the ends of the three-inch legs were welded to the column with a 5/16-inch bead. This welding was done in a downward direction by turning the column to typify shop fabrication. Four continuity plates, each 3 inches by 5/8 inch, and 6 5/8 inches long, were then located against the web of

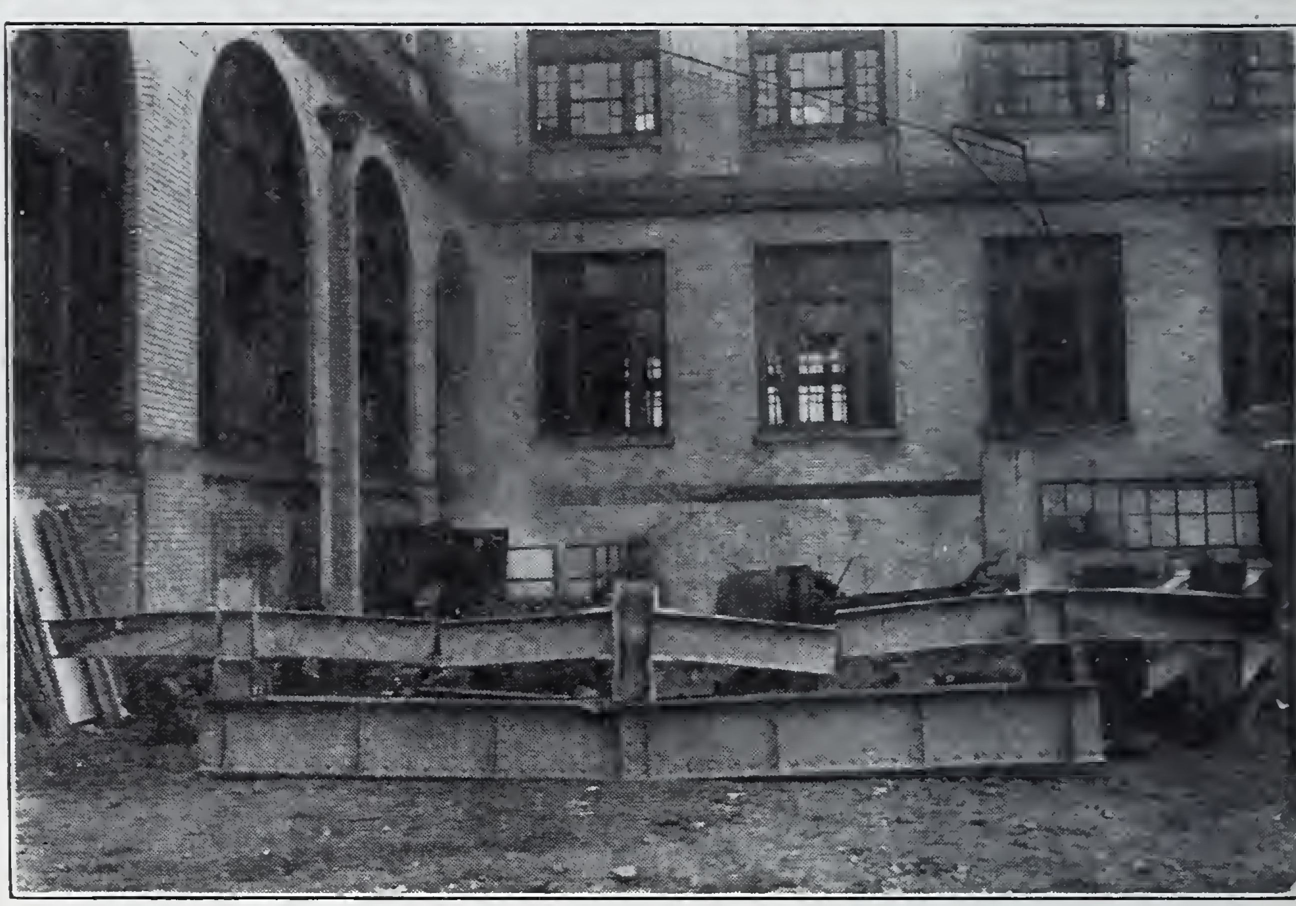

Fig. 1. Welded Specimens 2, 4, 3 (Left to Right, Above) and 20.

the column between flanges so as to be directly in line with the flanges of the cantilever beam. The column was turned to permit all downward welding the same as for the seat angles. These continuity plates were heavily welded, with a 3/8-inch fillet entirely around their ends, against the column flanges. The column was then placed on end and the I-beams were landed on the seat angles with approximately a 3/16-inch opening between the beam ends and the column faces. The entire ends of the beams were then welded to the column faces. Also the edges of the beams were welded four inches along the line of the outstanding legs of the seat angles. Two top

reinforcing plates (each 4 inches by ½ inch by 4½ inches) were then located on top of the beams with the four-inch lengths adjacent to the column faces. These ends were welded to the column faces and the 4½-inch lengths were welded to the top flanges of the beams.

Specimen 3 differed from 2 in that no seat angles and no reinforcing plates were used. Specimen 4 differed from 2 in the very vital item of omitting the "continuity" plates from the column flanges.

Each of these specimens was turned upside down and mounted on rocker blocks five inches wide located with their centers three inches from the beam ends, thereby providing a span of approximately six feet, 2½ inches, the load being applied on the upstanding end of the column.

The results of the tests are shown by Fig. 1, and the following table:

Specimen number	Elastic limit pounds	Ultimate load pounds	Bending moment at column face in inch pounds	Remarks on ultimate load
2	57,000	70,000	1,165,000	No. 2 = 31 per cent. higher than No. 4
3	50,000	68,550	1,130,000	No. 3 = 28 per cent. higher than No. 4
4	28,000	53,400	878,000	No. 2 = 2 per cent. higher than No. 3

It is interesting to observe that none of the specimens had a single failure in the welds. Specimens 2 and 3 failed by web crippling of the cantilever beams, and No. 4 by web buckling of the column. The fact that No. 2 shows two per cent. greater ultimate capacity than No. 3 is attributed to the stiffening effect both in the vertical and horizontal planes produced by the top reinforcing plates and the outstanding legs of the seat angles. The very marked difference between No. 2 and No. 4 is, of course, due to the "continuity" plates in the column of No. 2, which produce an effect identical with that of having the two cantilever beams carried continuously through the column. This construction is carried out completely through the Westinghouse building in Sharon.

To show the advantages gained by simply substituting arc welding for riveting in tension members, two specimens were prepared, designated as 17 and 18. Specimen 17 comprises two angles 2½ by

2 inches by 3/16 inch, and four feet long, with their 2½-inch legs located against two shank plates ¾ inch by 5 inches, and 12 inches long, with the angles overlapping the plate ends four inches. The heel and toe of each angle were welded along the four-inch length and across the ends of each angle to the shank plates. Specimen 18 differed slightly in that the angles were four feet, 2½ inches long, overlapped the shank plates by 6½ inches, and were riveted to the shank plates with six rivets ⅝ inch in diameter, power driven in 11/16-inch holes.

The welded specimen failed through the 2½-inch leg first, followed by tearing through the two-inch leg adjacent to the end of the shank plates. The riveted specimen failed through the first rivet hole at the end of the shank plate.

The following table gives the pertinent data:

Specimen number	Elastic limit pounds	Ultimate load pounds	Ultimate load in pounds per square inch of sectional area of the two angles
17	70,000	94,000	58,000
18	60,000	72,000	44,500

In addition to the fact that the welded specimen was more than 30 per cent. stronger than the riveted specimen, it is interesting to note in passing that the elongation of the welded specimen was 168 per cent. greater than the riveted specimen, the values being 1.12 inches over a length of four feet, 3½ inches for the riveted specimen and three inches for the welded specimen measured over a length of 40 inches.

Three simple beam specimens were constructed. For each of the three specimens identical superstructures to support the beams were constructed by arc welding, using 10-inch H-sections weighing 49.5 pounds per foot, the base section being nine feet, 7¾ inches long, and the column sections being two feet, three inches high. The "continuity" plates were ⅝ inch by 4 inches, and 8¼ inches long. The back stress plates tying the column faces to the base web were ½ inch by 6 inches, and one foot, four inches long. The beam member of each specimen was a nine-inch I-beam weighing 21.8 pounds per foot, seven feet, 11⅜ inches long.

In the case of specimen 7, two seat angles 3 by 4 inches by ⅜ inch, and five inches long were welded along the ends of the three-

inch leg to the columns. The structure was then turned in the upright position and the beam was landed in position on these seat angles. The beam ends were then welded to the column faces and landing angle. Reinforcing top plates 4 inches by 7/16 inch, and five inches long were also added and welded exactly as described for specimen 2.

Specimen 8 differs from 7 only in the omission of the seat angles and the top reinforcing plates for the beam-to-column connections.

Specimen 9 is materially different in that the beam-to-column connections follow standard riveting practice. Two top and bottom angles ½ inch thick, and a total of 20 rivets ¾ inch in diameter, power driven in 13/16-inch holes, were used.

Each of the specimens was centrally loaded on a block 1½ by 5 inches, and eight inches long, placed with the eight-inch dimension across the top flange of the beam. In each of the three specimens, failure took place by web crippling and flange buckling at the center of the beam. It is interesting to note, however, that in the case of the riveted specimen (No. 9), although the major failure was web crippling at the center of the beam, a preliminary failure by bending of the top angles produced a V-shaped opening between the beam end and the column faces. This preliminary failure of the top angles was responsible for the early ultimate failure of the specimen, as shown by the following table:

Specimen number	Elastic limit pounds	Ultimate load pounds	Remarks on ultimate load
7	50,000	73,500	No. 7 = 25 per cent. higher than No. 9
8	50,000	67,200	No. 8 = 14 per cent. higher than No. 9
9	42,000	58,700	No. 7 = 9 per cent. higher than No. 8

As in the case of specimens 2 and 3, we attribute the superiority of 7 over 8 to the stiffening effect, in both vertical and horizontal planes, produced by the top reinforcing plates and the outstanding legs of the seat angles.

In the case of specimen 7, the sum of the positive and negative bending moments was 1,760,000 inch pounds. As the welds showed no distress, and as the columns did not perceptibly deflect, the negative moment at either end must have been nearly as great as the positive moment at mid-span. For purposes of comparison with tests 8

and 9, assume this test a case of perfect fixed ends, positive and negative moments being each 880,000 inch pounds. This corresponds to a maximum fiber stress of 46,500 pounds per square inch.

For specimen 8 the sum of the positive and negative bending moments was 1,618,000 inch pounds. Assuming the same ultimate positive bending moment as in test 7, the negative moment at the column face would be 738,000 inch pounds, indicating 84 per cent. fixation.

For specimen 9 the sum of positive and negative bending moments was 1,410,000 inch pounds. Assuming the same ultimate positive bending moment as in test 7, the negative moment would be 530,000 inch pounds, indicating 60 per cent. fixation. Such a degree of fixation could not have been obtained with an ordinary type of angle 5/16 or ⅜ inch thick.

There is probably no more fertile field for the use of arc welding than that afforded by built-up members, such as girders, columns, etc., which exceed the sizes of existing rolled shapes. For this reason it was decided to build up a series of four specimen girders, as illustrated in Fig. 1-3.

The riveted specimen 20 (in foreground of Fig. 1) comprises a web plate 5/16 inch by 14 inches by 15 feet; four flange angles 3 by 4 inches by 5/16 inch; 16 web-stiffener angles 2½ by 3 inches by ¼ inch, and filler plates. A total of 116 rivets ¾ inch in diameter, power driven in 13/16-inch holes, were used to fabricate the girder.

Specimen 19 (Fig. 2, right) was constructed of the same parts, but assembled by arc welding. The top flange angles were welded to the web-plate by intermittent welds one inch long, spaced three inches from center to center, along the toe of each of the top angles. The backs of the angles were welded together and to the edge of the flange plates intermittently, using two-inch welds, spaced three inches from center to center. At each end, the angles were welded solidly to the web-plate at both the heel and toe for a distance of three inches. The bottom flange angles were welded to the web-plate solidly for a distance of six inches at each end of the toe, the remainder of the weld along the toe of the angle being two-inch lengths, five inches from center to center. The heels of these angles were welded solid, and also welded to the edge of the web-plate for a distance of six inches. The remaining portion of this same joint was intermittently welded

in two-inch lengths, five inches from center to center. The filler plates were welded to the web-plate by means of two-inch welds at the neutral axis and ½-inch welds at the ends of the filler plates along the web-plate. The stiffener angles were completely welded around the entire periphery, making contact with the flange angles. Two-inch welds were also made at the heel and toe of each of these

Fig. 2. Welded Specimens 19 (Right) and 21 (Left).

angles exactly in line with the two-inch welds made at the edge of the filler plates to the web-plate. The completed specimen weighed 785 pounds. The amount of welding wire required to complete the specimen was 27 pounds, eight ounces. The total time to complete the specimen was 14 hours and 10 minutes.

Specimen 21 (Fig. 2, left) was designed strictly to take all advantage of the possibilities of joining structural-steel members by

the use of arc welding to produce a girder of equal strength using less weight of steel. In this respect it is entirely different from 19, which is simply a riveted design, welded. Specimen 21 comprises a web-plate 14 inches by 5/16 inch, and 15 feet long; two flange plates 10 inches by 3/8 inch, and 15 feet long; and 16 web-stiffener plates 3 inches by 1/4 inch by 12 inches, and 1 3/4 inches long. The top flange was welded to the web-plate continuously along each side of the web-plate. The bottom flange was welded to the web-plate solidly for a distance of six inches from each end, and then by intermittent welds two inches long, four inches from center to center, the rest of the

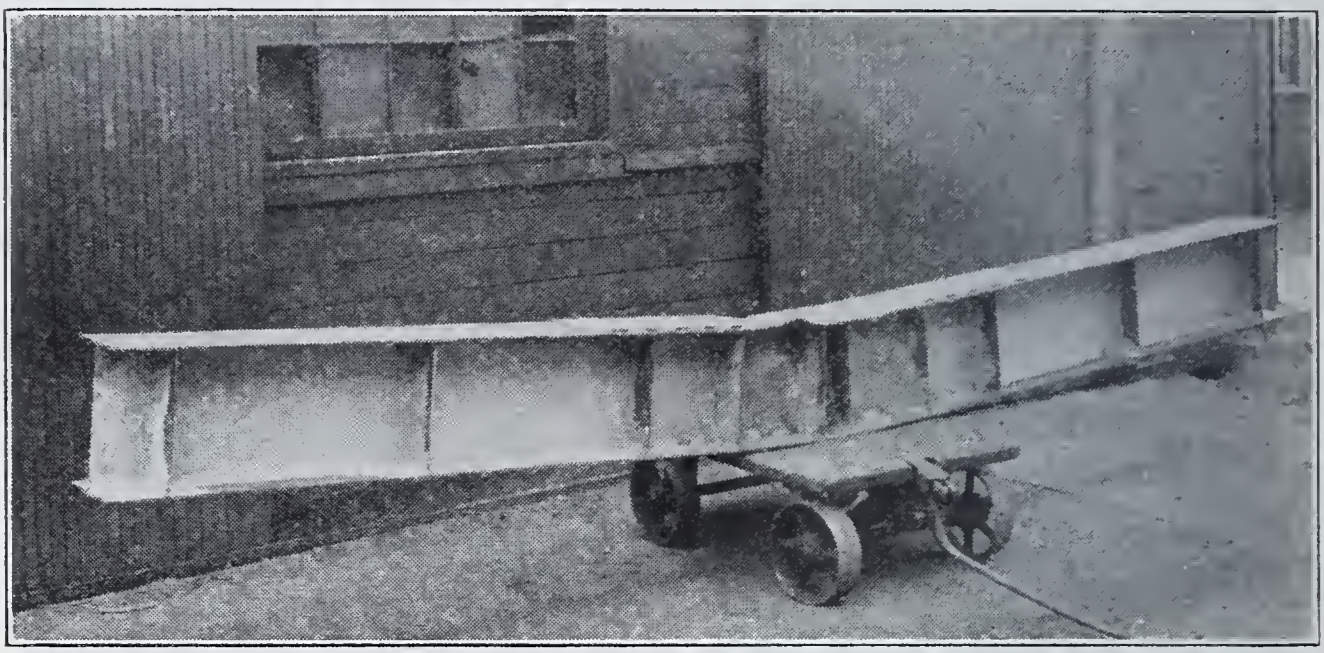

Fig. 3. Welded Specimen 21A.

distance on each side of the web-plate. The web stiffeners were welded solidly to the flanges around the entire periphery at each end of each web stiffener. Each web stiffener was also welded two inches on each side at the neutral axis, and at intermediate points one inch long at each side of each stiffener, half way between the neutral axis and the flanges of the girder. This specimen had a total finished weight of 656 pounds, which is 18 per cent. less than that of the riveted girder (specimen 20), which weighed 798 pounds; and 16 per cent. less than the riveted design welded (specimen 19), which weighed 785 pounds.

Specimen 21A (Fig. 3) was also designed to take all possible advantage of arc welding and to use an amount of steel having about

the same weight as the riveted girder (specimen 20). It is similar to specimen 21, except that the web-stiffening plates are 4½ inches by ¼ inch, and 14 inches long. The total number of web-stiffening plates used was 20, and a top reinforcing plate 9 inches by 5/16 inch, and six feet long, was welded to the top flange. This plate was welded solidly across each end and along each edge from the center of the girder to a point one foot, two inches from the center of the girder. The remaining length of the edge of the plate was welded intermittently by two-inch welds with centers four inches apart. This girder had a completed weight of 795 pounds, and required 30 pounds, 12 ounces of welding wire to complete the welding work. The total welding time was 16 hours and 50 minutes.

All of these girders failed in a very similar manner, principally by buckling of the top flange.

In the following table the record for specimen 20B is the average of the data for the two specimens 20 and 20A.

Specimen number	Weight pounds	Elastic limit pounds	Ultimate load pounds	Maximum bending moment foot pounds	Maximum fiber stress pounds per square inch
19	785	65,000	77,200	270,000	53,800
20B	798	57,500	71,450	250,000	49,200
21	656	65,000	78,000	273,000	52,700
21A	795	60,000	110,350	386,000	

Comparative data

Weight	Ultimate load
No. 21A is ½ per cent. below No. 20B	No. 21A is 59 per cent. above No. 20B
No. 21 is 18 per cent. below No. 20B	No. 21 is 9 per cent. above No. 20B
No. 19 is 1½ per cent. below No. 20B	No. 19 is 8 per cent. above No. 20B
No. 21 is 16½ per cent. below No. 19	No. 21 is 1 per cent. above No. 19

A few deductions of interest may be drawn from these girders; for example, since 19 and 20 are made up from duplicate parts, one should be as strong as the other. We find, however, that although 19 is slightly lighter, it developed eight per cent. greater strength. This is attributed to the fact that welded connections are much more rigid than riveted connections, but the feature of even greater importance is the fact that the heels of the flange angles were welded together and to the edges of the web-plate, which makes the two sets of flange

angles practically the equivalent of a solid plate, thus materially stiffening these members as compared with the riveted construction.

During the tests of these girders, none of the webs showed any signs of distress even at the points of maximum stress. Fig. 4 (specimen 21) shows the weld joining the web and the top flange at the point of maximum buckling.

Fig. 4. Welded Specimen 21.

All of these girders were tested by central loading on a bearing plate 1½ by 5 by 8 inches, placed lengthwise across the top flange of the beam.

SUMMARY

The data given in this article fully demonstrate the following facts:

1. Welded joints can be constructed in such manner as to develop fully the ultimate strength of the structural members connected.

2. Beams and girders can be connected to columns so as to produce absolute fixation.

3. Lines of beams or girders can be connected so as to provide complete continuity across the supports, whether the supports be girders or columns.

4. A steel I-beam of given section and length sustains a far greater load, if fixed at its ends by a suitably designed welded joint, than if supported by standard riveted connections consisting of top and bottom angles. A nine-inch standard I-beam framed between rigid upright columns eight feet apart, by means of specially designed welded connections, sustains a load 25 per cent. greater than a beam of the same size and length framed between columns by means of riveted top and bottom angles of ½-inch thickness.

5. A plate-girder assembled by welding and consisting of nothing but sheared plates has a far greater bending strength than a riveted plate-and-angle girder of the same weight, due to the better distribution of the steel in the cross-section. A 15-inch plate-girder assembled by welding and simply supported on a 14-foot span develops more than 50 per cent. greater strength than a riveted plate-and-angle girder of the same depth and the same weight.

6. A double-angle tension member, such as is used in trusses, was connected at the ends by welding, and when tested to tension failure broke through the angles at a load 30 per cent. greater than the load at which a hanger consisting of the same size angles with riveted end connections failed.

The prevailing impression among observers was that these tests demonstrated the superiority of welded connections to riveted connections in every case where direct comparisons were made, and brought out two general facts:

1. That complete continuity of lines of beams can be obtained in welded construction; whereas it is well known that this can not be done in riveted construction.

2. That in a welded building it will be possible to make every joint develop the full strength of the main members; whereas in a riveted building many joints are weaker than the members, due to the weakening effects of the rivet holes and the weakness of steel angles which have to be used for transmitting tension between two members at right angles to each other.

It was proved that a welded plate-girder was 50 per cent. stronger than the riveted girder of relative depth, length, and weight.

The joints recorded here are being used in the five-story steel building 70 by 220 feet, and 80 feet high, now being fabricated and erected by the American Bridge Company for the Sharon works of the Westinghouse Electric & Manufacturing Company. The typical beam and girder connections are fully continuous connections, thereby permitting a large percentage (about 12 per cent.) of saving in the weight of the beams and girders to carry a given load. The same type of connection which develops continuity also effectively stiffens the building against wind. The equivalent can not be obtained by any known riveted joint.

ACKNOWLEDGMENTS

The design of the test specimens described above, and the design for the welded steel building for the Westinghouse Electric & Manufacturing Company at Sharon, Pa., were produced by Mr. Gilbert D. Fish, Consulting Structural Steel Engineer, co-operating with the arc-welding engineers of the Westinghouse Electric & Manufacturing Company.

All material for these test specimens was furnished gratis by the American Bridge Company, and was specially prepared under the direction of Mr. Marshall Williams, Assistant to the President of that company. Complete data upon the physical properties of all of this steel, including tensile tests and chemical analyses, were also supplied, and great care was taken in selecting the steel material so that, in so far as possible, it would be from the same heat so as to secure uniformity in comparing the various specimens.

All of the testing work was carried on at the Carnegie Institute of Technology, on an Olsen machine of 400,000 pounds capacity, by Mr. J. M. Daniels, instructor in charge of the Materials Testing Laboratory, and his assistant, Mr. Arthur Haeppel. The actual welding of the specimens and all records of tests were carried out under the direction of Mr. A. M. Candy, Welding Engineer, and Mr. C. T. Eakin, of the Material and Process Engineering Department of the Westinghouse Electric & Manufacturing Company. This company hereby desires to record acknowledgment of the service rendered in this work by all of the above mentioned parties, and the assistants working under them.

DISCUSSION

R. B. HORNER:* I would like to ask what unit stresses are figured in designing the welded joints and what percentage of the weld it is permissible to use in determining the strength of these welded joints.

A. M. CANDY: In designing, we are using unit stresses of 2500 pounds per linear inch of 5/16-inch lead. We know from a large number of tests that have been made in arc welding that the present welding material will show 40,000 to 55,000 pounds per square inch in shear and tension, respectively, where mild steel is used. That gives us a factor of safety of over four, based on the ultimate of 40,000 pounds to the square inch. I believe that answers that question.

R. B. HORNER: I took that illustration where the I-beam had been broken away from the column. In that case you found that only about 40 per cent. of the metal gave any value in holding. Do you believe that it would be safe to figure on 40 per cent. of the welded seams?

A. M. CANDY: That is what we did in this building. That was intentionally made by a poor workman just to see what results might be expected. We are not leaving anything to luck in our buildings. Supervisors are inspecting the work as it goes along. We are using what we consider a conservative value for our design, and, in addition, in the shop fabrication and the field where the welds are specified two inches long we are making them 2½ and three inches.

A question was asked as to how we are going to get these buildings together. I did not explain that every beam has two holes at each end and the seat angles have two holes. In this building there are over 3000 erection bolts used for beams alone and a large number for the hangers on webs—probably 3500 to 4000 erection bolts in that structure, including column splices and all the other details.

C. S. DAVIS:† How are we to know when we are getting a good weld?

*Structural Engineer, Duquesne Light Co., Pittsburgh.
†Consulting Engineer, Pittsburgh.

A. M. CANDY: The best answer to that would be to have you go down with me to a place where they are doing welding and explain what we look for to determine whether the welding is being properly done. One thing to look for is the crater formed at the end of the weld. If the workman is thoroughly fusing into the member you can see the arc actually fusing the surface of the members to be joined. Look at the edge of the bead and if it is a feather edge with no overlap, and you have a good crater, you have a good job. If you observe the crater formed, if the operator is not getting into both members, and the metal is rolled out and by looking back under the edge you can see that it is not in contact, you know that you are not getting a good job. Between those two extremes you have a variation. If the supervisor who is in charge of the work is on the job with his men he can, by looking over their shoulders as they work, and by looking at the bead edges and arc crater, get a thoroughly good idea of what sort of a job is being done. If you could once see it you would realize that they are not working in the dark by any means. As an example, some time ago the American Bridge Company sent a sample down to Washington to be tested and we went over the welded joints and marked out places where we thought failure would take place, and in every instance where failure took place it was in one of the places that we had pointed out. It is simply a question of the use of discretion and good judgment.

C. S. DAVIS: It might be of interest to call your attention to some of the peculiar characteristics of the tests to which Mr. Candy referred. These came to me in an informal way, so I shall not be able to give you full information, but reports will probably be published in the near future. The girder was built from discarded material without any attempt to proportion the girder scientifically. The web plate was, I believe, ½ inch thick; the flanges were made of eye-bars that had been used for full-sized tests. The outer flange plate was narrower than the inner, to permit of better welding along the edges of the outer plates. All stiffeners were made of bars; no angles were used. When this beam was tested, it behaved naturally up to a point of incipient failure, but beyond that point eccentricities occurred. Some portions of the bottom flange plates developed compression

stresses—a condition which is rather hard to understand without a careful study of the case.

F. J. EVANS:* Assuming that the joint is improperly made, and does not pass inspection, is there a satisfactory way of correcting that condition?

A. M. CANDY: The way to correct it is to chisel it out. Our inspectors are instructed, when any material indicates that work is not properly done, to get busy and chisel it out and do the job over again. That is the only way to do it. It is like a rivet that is improperly driven, the only thing to do is to cut it out.

A. W. ENGEL:† I would like to ask what effect the presence of paint or rust has on the making of welded joints?

A. M. CANDY: If the paint is not too thick and of the right kind it does not have any effect. Of course, we would prefer to have steel right from the mill without any rust or paint on it; but it is not a serious matter, because good welders always clean off the material with a wire brush. A light coat of ordinary red-lead paint does not interfere to any extent with the welding operation, but you get lead oxid and there is danger of poisoning the operator.

While I am on my feet I should like to speak of one thing which Mr. Davis mentioned. It was found that the upper plate of the lower flange showed compression. The main flange plate of the upper flange showed tension where you would ordinarily expect compression.

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†Engineer, American Bridge Co., Pittsburgh.

RECOVERY OF PETROLEUM AND NATURAL GAS THROUGH OVERLYING COAL-BEDS*

By W. E. Fohl†

Aside from any question of the relative values of the three sources of energy indicated in the title of the paper, it will, I believe, be readily admitted that the need for each of them is so urgent that, wherever one or the other of them is found in workable quantity—or all of them simultaneously—means for recovery must also be found. A brief review of the difficulties incident to their simultaneous recovery, of the methods in use, and of certain suggestions in connection therewith, is the purpose of this paper.

The inflammability of petroleum and the explosiveness of natural gas when diffused in atmospheric air have created a wholesome dread of the consequences of their admission into operating coal-mines. That there is reasonable basis for this dread is shown by the following list of accidents attributable to the presence of petroleum or natural gas in mine workings. So far as I know, this list contains all the accidents of which accounts have been published, as well as those disclosed in answers to a questionary which I have recently sent to a considerable number of members of the American Institute of Mining and Metallurgical Engineers who might be supposed to have first-hand information on this particular subject. It will be noted that the list gives date of accident, place, number of fatalities, and proximate causes.

1. July 30, 1912. Vandergrift, Pa. Lewis mine, Pine Run Coal Company. No fatalities, but serious mine fire resulted from striking an abandoned and unmarked well while undercutting coal with chain machine. Gas ignited by open lights of machine runners.‡

2. December 19, 1910. Enterprise, W. Va. Mines 47 and 49, Consolidation Coal Company. Three fatalities. Two explosions of

*Presented January 18, 1927. Received for publication March 15, 1927.

†Consulting Mining Engineer, Pittsburgh.

‡Items 1-11 excerpted from paper of L. M. Jones read before conference of coal, natural gas and petroleum operators, and representatives from state geologists, state mine inspectors, and United States Bureau of Mines, held at Pittsburgh, February 7 and 8, 1913. Proceedings of this conference later published in United States Bureau of Mines Bulletin 65.

gas forced through strata beneath coal-bed, from a well which had been completely capped at surface. Removal of cap from outer casing relieved pressure and permitted gas leaking from tubing to find outlet to surface instead of into the mine. Gas which exploded ignited by open lights of miners.

3. November 22, 1912. Peoria, W. Va. Country mine. Two boys killed, one man seriously burned. Explosion of gas forced into mine by nearby well which had both casing and tubing capped. Opening of valve in casing removed gas from mine. Ignition by open lights used by miners.

4. Undated. Reynoldsville, W. Va. Country mine. No fatalities. Violent explosion followed a blasting shot. A capped well 1000 feet from mine opening was opened without cutting off gas from mine, but gas disappeared when one 1500 feet distant was uncapped.

5. Prior to 1911. Clarksburg, W. Va. No fatalities reported. Explosion in mine, only 80 feet from outcrop. Report by Mr. Frank Parsons, district mine inspector, who concluded that it was an explosion of natural gas because a nearby mine had been worked without finding gas and, since its abandonment, four gas wells had been drilled in the neighborhood. Statement seems far from conclusive.

6. Prior to 1913. A mine in southwestern Pennsylvania. Analysis of mine air near an abandoned well, located in a pillar near the forks of two entries, showed, in 1911, leakage of natural gas into mine at rate of 252 cubic feet a minute. Analysis in 1913 still showed gas, but in decreasing amount. No statement concerning well outlet at surface.

7. October 17, 1895. McDonald, Pa. Brier Hill mine. Three men badly burned, one dying 12 days later. An oil-well had been drilled, two years before, through a section of the mine in which pillars had been drawn. Pillar drawing was stopped, but the coal left in was insufficient to halt a creep, which caused a horizontal movement of the strata, resulting in rupture of the casing, tubing, and pump-rods of the well. Gas entered the mine, but, as the casing at the surface was connected with a gas line, it is uncertain whether the

gas exploding in the mine came from the strata below the coal or from the gas line on the surface. Ignition was from open lights carried by the men who were burned.

8. Prior to 1913. Unnamed mine in western Pennsylvania. Drawing of room pillars surrounding an oil-well bent the casing to such a degree that it was no longer possible to operate the rods in the well. No casualty reported.

9. Prior to 1913. Unnamed mine near Pittsburgh. Casing of abandoned well between tracks on a parting. Filled with cement from a point fifty to sixty feet below floor of mine. Badly bent by wrecking of trips. Gas and salt water came up outside of casing. No casualty reported.

10. Prior to 1913. Bergholz, Ohio. Rice mine. A well was drilled through a room in the mine and casing driven 10 feet below the coal. Oil and gas being struck 700 feet farther down, they came up outside the casing and entered the mine through crevices in the bottom. A second and inner string of casing with rubber packers running from a point 60 feet below the coal to the surface with cementing between the two strings of casing stopped the inflow. No casualty reported.

11. Prior to 1913. Unnamed mine in Pittsburgh district. Oil oozed into working rooms from clay seam through which mine had passed. Source appeared to be in one or more of three abandoned wells within a distance of 400 feet. No natural gas accompanied the leak. No casualty reported.

12. 1922. Canon City district, Colorado. Mines have struck oil which continued to flow for several months. Among these are the Rockvale and Coal Creek mines of the Colorado Fuel and Iron Company. A flow of oil struck in Coal Creek mine, 1922, produced 25 barrels a week and caused a disastrous mine fire. No casualty reported.*

13. 1894. McDonald, Pa. Laurel Hill mine No. 1. Serious fire caused by breaking of casing and tubing of well which had been

*Safeguarding coal-mining operations against danger from oil and gas wells, by A. W. Hesse. Trans. A. I. M. and M. E., February 1925.

drilled through old workings. In same mine on another occasion leakage of oil into mine was discovered in time to prevent accident, but part of mine was out of use for considerable time. No casualty reported.*

14. Undated. Washington County, Pa. Midland No. 3 mine, Pittsburgh Coal Company. An inflow of gas was traced to a gas well on a nearby reserve which was found to have its outflow pipe frozen. On opening the pipe, gas soon disappeared from the mine. A masonry chamber built around the well with provision for water drainage and a vent hole drilled from the surface has prevented any inflow of gas since. No casualty reported.

15. September 21, 1915. Wilsonburg, W. Va. York mine, Hutchinson Coal Company. A mild explosion of gas at this mine resulted in the death of one man—the mine foreman. Suspicion being directed to a nearby producing gas-well, it was found that with the well closed and the mine sealed, explosive gas was present in the mine. With the mine sealed and the well discharging into the air, no gas was found in the mine. A 10-inch casing had been set and cemented in this well, supposedly 20 feet below the Pittsburgh coal-bed—the one being worked. It developed, however, that in setting this casing, the Redstone coal had been taken for the Pittsburgh, so that the base of the 10-inch casing was actually five feet above the top of the Pittsburgh coal. Outlets were provided which permitted the 10-inch casing and the next one inside (6⅝ inches) to discharge into the open air, after which no gas was found in the sealed mine. It was obvious that relief was solely from the discharge from the 6⅝-inch line, from which the discharge was approximately 10,000 feet a day.†

16. In this same mine, gas was found in considerable quantities four years before. Traced to a nearby well, it was removed by merely opening to the air its outside string of 8¼-inch casing.

Summarizing the foregoing list, we find cited between 1894 and the present date 16 cases of intrusions of oil or gas into coal-mining operations, resulting in nine casualties, seven of which were fatal.

*Items 13 and 14 reported by J. M. Rayburn, Pittsburgh.
†Investigation by author.

A further summary, with relation to causes, taking the accidents in the order of their citation, shows as follows:

	Condition of well	Method of ignition
1.	Uncharted, unprotected well	Open lights
2.	Outside well casing capped	Open lights
3.	Outside well casing capped	Open lights
4.	Outside well casing capped	Blasting
5.	Unknown	Unknown
6.	Unknown	No ignition
7.	Ruptured by creep in mine. Outside well casing capped	Open lights
8.	Casing bent by pillar drawing, putting well out of use	No ignition
9.	Abandoned well in middle of mine entry. Casing bent by mine-car wrecks, causing leakage of gas and salt water	No ignition
10.	Well cased 10 feet below coal pushed gas into mine from sand 700 feet lower. Inner casing set with rubber packer 60 feet below coal stopped leakage	No ignition
11.	Abandoned wells forced oil into mine through clay seam	No ignition
12.	Fire from oil encountered in mining	Unknown
13.	Well ruptured by pillar drawing	Unknown
14.	Outlet pipe from well frozen	No ignition
15.	Outside well casing capped	Open lights
16.	Outside well casing capped	No ignition

The significant facts here are that, for the most part, troubles have arisen from wells that were improperly located, or improperly protected from the results of mining operations, or so shut in that the perssure on the wells intruded oil or gas into the mines, either through openings in the coal itself, or through the strata beneath the coal. Of especial significance is the fact that, in the nine cited cases where ignition occurred, it was caused in five of them by open lights and in one by blasting. In the other three, marked unknown, the causes were probably known, but have not been reported. There is little reason to doubt that ignition in these cases was from the same causes.

One of the most dreaded hazards of coal mining is the encountering of the uncharted well. Many of these have been drilled in virgin coal territory, abandoned without proper protection, and with no record of their exact location. There have been many instances of encountering such wells the existence of which was completely unsuspected. Only a few of them have found their way into the printed record because, fortunately, in the majority of the cases igni-

tion did not result. This negligence, highly reprehensible, if not criminal, is the result of the ease with which it has been possible, in most states, for people with small capital, and less knowledge of the hazards of the business, to engage in the drilling of oil- and gas-wells. A movement sponsored by the American Institute of Mining and Metallurgical Engineers is now under way, having for its object the calling to the attention of the various state legislatures the necessity for regulating this, as well as other features incident to the simultaneous recovery of coal, and petroleum or natural gas from the same territory. It is expected that the report of the committee engaged in this work will be published soon.

When more than half the ordinary bituminous, or lower rank, coal-bed is removed over any considerable area, the stability of the overlying strata is threatened, regardless of the character of the strata. When such a coal-bed is mined by present-day methods, under which recoveries of 90 per cent. of the bed are not at all uncommon, the subsidence of overlying strata is certain, regardless of their character or thickness. While, in the main, this subsidence is vertical, it is frequently accompanied by preliminary torsional movements; and, at its close, the strata are frequently found to have made a considerable shift horizontally. The danger to the piping contained in an active oil-well or gas-well is thus readily apparent.

No better protection against the danger of rupturing this piping has been proposed than the leaving of a solid pillar of the coal itself surrounding the well. Opinions concerning the proper size of this pillar, however, are widely variant. The extreme limit proposed, and actually in use in certain districts, is a pillar 200 feet square, having an area of 0.92 acre, and of an unvarying size under both light and heavy cover. In a five-foot bed of coal—the average thickness of the Pittsburgh bed in our immediate vicinity—this entails the irreparable loss of nearly 7000 tons of coal for protection of a single well. I believe this to be a waste of nature's stored power, and an excessive burden on whichever one of the three industries is called upon to include it in its cost of production.

As to a proper size for such protecting pillars, I quote from a previous contribution of my own to the *Transactions of the American Institute of Mining Engineers*.*

*V. 50, p. 870-872.

The protection of a well is analogous to the protection of a shaft, except that protection for the latter ordinarily comprehends support for the more important units of the surface plant. The size of pillar actually requisite for these purposes is not susceptible of mathematical calculation, as it is impossible to forecast either the volume or the direction of the forces which will impinge on the pillar during the subsidence of the overlying strata. These can only be estimated, and the following table will show how widely authorities on mining have varied in the estimates they have made in this connection. It will be readily seen that there is no consensus of opinion among the seven authorities quoted as regards any given depth, and it will also be apparent that there is no regularity of disagreement in progressing from the minimum depths to which their formulæ have been applied in the preparation of the table.

Sizes of Shaft Pillars in Accordance with Formulæ of Various Mining Authorities for Depths from Surface

	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet
Depth from Surface	100	200	300	400	500	600	700	800
	Length of side of square pillar							
Merivale	38	54	65	76	85	93	101	118
Andre	105	105	105	105	121	135	154	175
Wardle	120	120	120	130	156	180	204	231
Pamely	120	120	120	145	169	195	220	244
Foster	159	224	275	317	355	389	420	449
Dron	67	133	200	267	333	400	467	533
Hughes	100	200	300	400	500	600	700	800

In 1910, acting in conjunction with the late James Blick, sometime Inspector of Mines for the State of Pennsylvania, the writer advised the leaving of pillars for the protection of oil and gas wells as shown in the subsequent table. This table was intended for use in the mining of the Pittsburgh seam of coal in West Virginia where it had an average thickness of seven feet and where the extreme depth of cover was 700 feet.

Pillar Sizes Suggested by Blick and Fohl

Cover Feet	Size of pillar Feet square	Area Acres	Cover Feet	Size of pillar Feet square	Area Acres
20	40	0.04	300	120	0.33
30	50	0.06	350	125	0.36
40	60	0.08	400	130	0.39
50	70	0.11	450	135	0.42
60	80	0.15	500	140	0.45
100	90	0.19	550	145	0.48
150	100	0.23	600	155	0.55
200	110	0.28	650	165	0.62
250	115	0.30	700	175	0.70

The pillar sizes set forth in this table were offered tentatively, with suggestions for tests of their efficacy, and for observations of the results of subsidence which would indicate whether they were adequate for their purpose. This information has not been secured, or, at any rate, has not been assembled and applied in the fixing of sizes for well pillars. This fact, and the lack of uniformity in sizes of pillar now being used, give warrant for the foregoing quotation.

The protection thus far discussed is that required to prevent the destruction of the well, entailing the loss of its production, and, conceivably, diverting that production, under pressure, into occupied mine workings; hence the necessity for preserving the well intact as an unobstructed outlet for the liquid or gaseous products it has released.

Even with the well intact, however, there may be leakage into mine workings, if all the annular spaces between the various lines of pipe introduced into the well are closed, either at the surface or some other point above the coal-bed. The importance of keeping open to the surface an annular space between the coal-bed and the first line of pipe which is carried below the coal-bed, presumably into oil- or gas-bearing strata, has long been understood; the accidents to which your attention has just been directed emphasize the necessity for this precaution.

The model act framed by the 1913 conference referred to in the foot-note on page 119 specified that a well passing through a workable coal-bed should be started with a hole of a diameter six inches greater than the inside diameter of the outside casing to be put through the coal-bed. This hole of larger diameter was to be carried 30 feet below the coal, and the annular space (presumably a little less than three inches across), between the circumference of the hole and the casing to be introduced into it, was to be filled with puddled clay, or with cement mortar, consisting of one part Portland cement and two parts clean sand properly mixed. An additional requirement was that this cementing, or puddling, starting 30 feet below the coal-bed, was to be continued to a point 30 feet above the coal, for the stated purpose of excluding water from the coal-bed; but, also, with the idea in the minds of the framers that it would act as a preventive to corrosion of the casing, and, perhaps, seal off gas even after corrosion had destroyed the effectiveness of the casing for that purpose.

While this method of protection was being used by some of the

more advanced oil and gas companies when this model act was framed, and has been largely used since, there has always been some doubt concerning its value. It has been argued that irregularities of the hole would form points of contact with the casing, breaking the continuity of the seal; and that little information could be had concerning the setting of cement mortar, lowered to great depths, whether poured directly into the annular space or into it through a two-inch pipe extending to the bottom of the hole and withdrawn as the space filled.

The condition of the two wells recently uncovered and examined by Mr. A. W. Hesse, Chief Engineer of the Buckeye Coal Company, was not reassuring on the point last mentioned. These wells, passing through the Nemacolin mine, had been carefully cemented by pouring through a two-inch pipe; but in one instance the mortar was found to be a light-weight, porous, artificial sandstone, while, in the other, the casing was found to be surrounded with material having the consistency and appearance of unconsolidated fire-clay. In neither instance was the protection effective for the purposes contemplated.

The difficulty and expense of such an attempt to interpose a seal between the coal and the well would be multiplied in cases where more than one bed of coal had to be taken into account. That it is necessary to consider this is shown by some of the drillings in Pennsylvania.

I have been furnished with figures from the log of one typical Greene County well showing the points at which were encountered seven beds of coal—four above the Pittsburgh coal, and two below it. None of these beds was shown to have a thickness less than three feet, and some time in the future coal-beds of this thickness must be taken into serious account, even in this bountifully supplied region. In corroboration of this statement I quote the closing paragraph of a letter from Dr. George H. Ashley, State Geologist of Pennsylvania, written in reply to an inquiry concerning the mining of thin coal-beds. He says:

It would appear that beds 12 inches and even less thick will be mined some time in the future, after the exhaustion of our thicker beds of coal. Mining operations in England and elsewhere show that there is no *physical* reason why these beds may not be mined. On the other hand, in this state it may be doubtful if much coal under 18 inches thick will be mined commercially within the next 50 years. By that time it is probable that about all of the four-foot coal in Pennsylvania, outside of the Pittsburgh bed, will have

been exhausted, and most of the mining outside of the Pittsburgh bed district will be on coals ranging from 2 feet to 3½ feet; with here and there smaller mines, or mines of unusually high quality coal, reaching down to 18 inches and possibly below.

Of the two intrusive agents we are considering, natural gas is the more mobile and any safeguard effective against it is more than equally effective against oil intrusion. It has been necessary for the mining industry to study carefully how to protect itself against explosive gas long before any danger existed from natural gas originating in the strata beneath the coal, as the coal seams themselves are in many cases reservoirs of gas which, while it differs considerably from natural gas in chemical composition, is violently explosive when mixed with atmospheric air in about the same proportions.

Coal-mines have long been roughly divided into the two classes, gaseous and non-gaseous; but it has long been known that mines ordinarily classified as non-gaseous are more likely to suffer from disastrous explosions than those which are recognized as gaseous and, consequently, more cautiously worked.

A laudable effort to limit further the dangers arising from this loose classification is displayed in a recent notice from the United States Bureau of Mines, known, I believe, as Decision No. 3. This decision deserves the widest possible publicity and consideration; accordingly, I am including it herewith in its entirety:

The (U. S.) Bureau of Mines believes that all coal mines are potentially gassy; but for purposes of administration in respect to prevention of explosions and fires, the Bureau recommends the following classifications:

Class 1 Coal Mine; a practically non-gassy mine in which inflammable gas in excess of 0.05 per cent. can not be found by systematic search.

Class 2 Coal Mine; a slightly gassy mine in which

(a) inflammable gas has been found,* but in amount less than 2 per cent. in still air in any active or unsealed-abandoned workings; or

(b) inflammable gas can be found, but in amount less than 4 per cent., in some place from which the ventilating current has been shut off for a period of one hour; or

(c) inflammable gas can be found,** but in amount less than ¼ per cent., in a split*** of the ventilating current; or

(d) inflammable gas enters a split*** of ventilating current at a rate**** of not more than 25 cubic feet per minute.

Class 3 Coal Mine; a gassy mine in which inflammable gas is found in amount greater than specified for a Class 2 Coal Mine.

* By employing an approved flame safety lamp, with flame drawn low, or by employing an approved gas detector, or by sampling and analysis with an approved gas analytical apparatus.

** By sampling and analysis with an approved gas analytical apparatus, or by employing an approved gas detector.

*** If but one continuous ventilating current is employed in a mine this shall be considered a "split" for the purpose of this definition.

**** Determined by sampling, analysis and ventilating-current measurement.

General Notes Regarding Decision No. 3

(A) The inflammable gas found in coal mines is, with rare exceptions, methane. In coal mining fields where natural gas is found in lower geological horizons by deep wells which pass through or nearby the coal mines, there have been rare instances of a leakage from the well. Natural gas is chiefly methane, almost always more than 85 per cent. is methane, but it usually contains ethane, propane and traces of butane. Therefore if the latter gases are found in mine air it is an indication of leakage. The lower limit of explosibility of methane-air mixture when there is turbulence is 5 per cent. and of natural gas-air mixtures with about 10 per cent. ethane and associated hydro-carbon gases is 4.6 per cent. The limit therefore varies with the character of mixture.

(B) To determine the proper classification of a coal mine, it is advisable that systematic testing and sampling be done at least three times in a period of not less than 72 hours. All tests and samples of the mine air, except one, must show an inflammable-gas content less than the maximum limit of the class to which the mine is assigned. In other words, a tolerance of one test or analysis may be permitted to provide for a mistake or a very exceptional occurrence.

(C) When a new mine is being opened in a coal field where existing mines are generally gassy, it is common sense to assume that similar conditions will be found in the new mine, and its development and equipment should be based upon the expectation that it will be assigned to Class 3.

I am particularly impressed with the appeal made to common sense in Remark (C), just read, but I believe that it should be followed by a fourth remark, which might be designated as Remark (D) and which would read as follows:

(D) When a mine is being operated in a coal field underlaid with strata known to be oil or gas bearing, it is common sense to assume that at any time during its life, conditions are likely to be encountered which will place it in Class 3; and its development, equipment and operation should observe precautions based upon this assumption.

The question of payment of the cost of the precautions adjudged necessary to protect mines and miners from injury has not yet been fully settled. It would seem at first glance that the party who lets loose a known danger should be the one to pay the cost of confining it within circumscribed bounds; but closer scrutiny indicates that there should be exceptions to this natural assumption. For example, it will be readily granted that the owner of a property underlaid with coal and petroleum or natural gas has the right to dispose of it in the market most favorable to him, and to dispose of the separate portions of it in any order he may choose. Should he choose to dispose of his oil and gas rights first, it is patent that he will receive a higher price for them if he burdens them with no restrictions having to do with the subsequent mining of the coal. Having thus received the full value of the rights first sold, he has no reasonable grounds for complaint if, later, he must accept a lesser price for his coal which is now to be sold with no protection against dangers arising from his first sale. Neither would it appear that the last purchaser would have any just complaint against the first purchaser, as he would be presumed to have investigated the prior sale, acquainted himself with the fact that protection for the coal had not been reserved, and to have received on this account an abatement of the purchase price. It appears to follow, in such a case, that the cost of precautionary measures should be assessed to the last comer.

This paper makes no pretense of being a full discussion of a subject which has only really begun to receive the consideration to which it is entitled, and concerning which there still remain many divergent opinions. In summarizing these rather scattered remarks on it, I shall restate, briefly, the facts touched upon, as well as certain conclusions which appear to me to arise from them.

Considering the length of time during which an uncounted number of oil- and gas-wells have been drilled through working coal-beds, the accidents incident thereto have been surprisingly few. It would not be wise, however, to let knowledge of this fact lull us into a feeling of security—a lack of vigilance by either of the industries concerned may constitute an invitation for the visitation of a major catastrophe.

The summary of the causes for the accidents cited calls particularly for a precise location for all wells passing through coal-beds,

whether they are now to be classed as workable or not. These locations should be made a matter of permanent public record, open for the inspection of those concerned with any one of the three industries interested.

It calls for providing, in every active well, a vent to the surface, which shall be open at all times for the escape of its liquid or gaseous products.

It calls for the sealing off below the coal of all of the oil- and gas-bearing strata, when a well is abandoned, in such a manner that the well shall no longer form an outlet for their remaining contents; and, while none of the accidents cited calls attention to the danger of water accumulation in the hole above the coal, it is a real menace to be guarded against by suitably filling the hole from coal to surface.

It calls, too, for the abolition of the open light, and for safe methods of blasting in all mines penetrated by oil- or gas-wells.

Protective pillars of the size tentatively suggested may not in all cases resist the compression incident to final subsidence of the strata overlying the coal, but they are intended to furnish protection against the intrusion of oil or gas while work is being prosecuted in their vicinity and while open spaces still exist around them.

I have discussed at some length the matter of cementing between the coal-beds and the outside casing of wells drilled through them because much stress has been laid on it in previous treatment of the subject under discussion, as well as in current practice. It appears to me to be of extremely doubtful value, and exceedingly difficult of application when account is taken of the several potentially workable coal-beds through which so many wells are drilled.

It is only fair to the coal-mining industry to say that the precautions indicated in Remark (D)—which I have proposed as a desirable addition to United States Bureau of Mines Decision No. 3—are being adopted in more and more mines each year, without waiting for the threat of danger from oil-wells and gas-wells.

With the same thought of fairness to the other industries concerned, I have offered the brief discussion as to the financial responsibility for the precautions which must rightfully be taken for the safeguarding of human lives.

ECONOMICS OF COAL-MINING*

By N. F. Hopkins†

Stone coal, as it used to be called, is of comparatively modern use. Until the age of steam arrived, there was sufficient wood to supply fuel, and sufficient charcoal could be provided to smelt the ore for making plowshares or swords as the occasion might demand. Probably if George Washington, while scouting the hills of Western Pennsylvania and Virginia, had noticed a seam of coal outcropping in one of the gullies, he would have noted it merely as an exemplification of the munificence of nature in furnishing resources that could never be utilized.

The invention of the steam-engine, and especially the steam locomotive and later the steamship, created a demand for fuel that could not be supplied by the forests, although as late as the Civil War many of the locomotives and most of the river steamers were wood burning.

Making of rails and iron bridges also increased the demand for carbon far beyond the capacity of the charcoal industry, and coke took the place of charcoal in steel making.

Just prior to the Civil War considerable progress had been made in extracting oil from coal so that coal-oil, kerosene, or carbon oil, depending upon whether you lived in Missouri, New York, or Pennsylvania, was beginning to take the place of whale-oil and the tallow candle. The discovery of petroleum destroyed this business, however, or rather delayed it for a century. It is probable that coal products will furnish the automobile of 1960 with its "gas."

The coal business has grown from the very small beginnings of one hundred years ago until, to-day, it is one of the four essential industries—agriculture, manufacturing, and transportation being the others.

Along with the growth of the industry there has been a growth in the size of the units or individual companies, but there are still many small and medium-sized companies.

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†Harrop & Hopkins, Pittsburgh.

The investments required in opening a coal-mine are as follows:

1. The raw material; that is, the coal in the hill.
2. The mine opening, and development, tipples, etc.
3. The mining machinery.
4. The housing of employees.

There are then the following expenses in the production of coal:

5. Supplies.
6. Labor.
7. Insurance and taxes.

1. The raw material, or the coal in the ground, is sometimes purchased with the surface, sometimes purchased separate from the surface, and sometimes paid for on a royalty basis as it is mined out.

Bituminous coal weighs about eighty pounds per cubic foot, which makes an acre foot of coal weigh 1740 tons. Under old conditions, when ribs were not drawn, it was customary to estimate the recovery at about 1000 tons per acre foot, or a recovery of about sixty per cent. Better mining methods give 100 tons per acre inch, while the best mining methods give a recovery of 85 per cent., or 1500 tons per acre foot. A five-foot vein of coal, therefore, gives 6000 to 7500 tons per acre. The price of coal varies from $5 to $5000 an acre, depending largely upon the location and quality.

The royalty ranges from 5 to 50 cents a ton. A royalty of 10 cents a ton is equivalent to $750 an acre of five-foot coal. This does not mean, however, that this coal is worth $750 an acre. Its present worth depends upon the speed with which it may be dug out. Estimating 25 years as the life of the average coal-mine, and with money at six per cent., would give $380 as the present value of an acre of coal. Expressed another way, a five-foot vein of coal, worth $500 an acre, is equivalent to 13 cents a ton royalty. Roughly, the value per acre is from 3000 to 5000 times the royalty per ton. It may be remarked that a royalty of seven cents a ton, or a value of $250 an acre, is about the minimum figure at which it is justifiable to open up coal for mining.

There are so many other items that make up the cost of coal-mining that one may be justified in mining coal costing $1000 an acre

in a good location rather than to attempt to mine coal that can be gotten for $100 an acre. Like cheap land and cheap labor, cheap coal is a poor investment—that is, as a mining proposition; as an investment for future development it may be all right.

2. The cost of mine opening, including sidings, tipples, slopes or shafts, fans, pumps, development, etc., varies greatly, depending largely upon the depth of the coal.

For coal of tipple height, self draining, and adjacent to the railroads or slackwater, the cost is a minimum. Under present conditions, it is seldom below $150 an acre (four cents a ton), and frequently is $250 an acre (seven cents a ton), depending largely upon the acreage that may be brought to the tipple. For deep shaft mines requiring long railroad lines to reach the field, the cost may run to $600 an acre (16 cents a ton). Between these two extremes are mines requiring long inclines to bring the coal down to the tipple, or shallow slopes to bring the coal up. When the mines are below water-level, there is usually a distinct advance in the cost of this item.

3. Mining machinery includes wagons, motors, mules, cutting machines, mine tracks, small tools, etc. The cost of this item will run around 5 to 10 cents per ton. If loading machines are used, the cost may go to 25 or 30 cents per ton. Loading the coal in underground workings is still largely a matter of hand labor. It is true that there are machines that will load coal where there is reasonable head room, but the difficulty is to get the mine-car away and an empty one in its place again with sufficient rapidity. It can not be done in the ordinary room-and-pillar method in use in the Pittsburgh district. Modification of the long-wall method appears to offer the best situation for the use of the mechanical loader.

A modification of the hand-loading method, now being looked into, is loading by hand onto belts or shaking carriers to take the coal from the working place to the entry, and load it into cars. The cutting machine is a great labor saver, though some pick mining is still necessary. The motor has not entirely supplanted the mule, but has made possible long hauls that could not have been made by horse-drawn cars. If loading machinery can be perfected, then mining will be less laborious, though there are thousands of acres of coal and millions of tons that must still be mined by hand. There is one class of mining where the machine is pre-eminent. That is the stripping

operation. Where there is less than 50 feet of cover over the coal, and not too much rock, the cover can be removed by means of a giant shovel and the coal loaded by means of a smaller shovel into cars for hauling to the tipple. The coal is sometimes loaded directly into railroad cars, but this is not desirable, even where it is possible, on account of the dirt unavoidably scooped up with the shovel. Picking of strip mining coal is necessary. It is estimated that six feet of cover can be removed to justify the recovery of one foot of coal.

In strip mining, it is necessary to buy not only the coal, but the surface as well—usually a much greater area of surface than is underlaid with coal—so that the principal items of expense in strip mining are the cost of the coal (item 1) and the mining machinery (item 3). These sometimes amount to 50 cents to $1 per ton.

4. In small mines situated close to a town there may be no effort made to house employees, but usually it is necessary to furnish housing facilities. This is a considerable item of investment, especially if the housing is entered into with the modern idea of providing comfortable and desirable quarters.

If the housing is undertaken with the idea of making it pay for itself—that is, have the rental return the cost of investment—the buildings will have to be constructed in a very cheap manner. This is, however, contrary to the modern idea of providing comfortable and sanitary dwellings for employees, so that a considerable amount of the cost of housing will have to be charged directly to mining. There is no doubt that, with the wages paid the miner to-day, he ought to be willing to pay more for his house, but there are few miners who are willing to pay for comfortable and sanitary surroundings more than they would have to pay for quarters that are merely habitable. In fact, few workmen of the same character in any other line of work will pay $30 for the best if the poorest costs but $20. The only direct return for the additional money spent on better housing is, therefore, in the better health of the miners' families; the consequent better health of the miners themselves; and the probability that a better class of miners may be obtained. It must be borne in mind that the life of a mining town is from fifteen to forty years, and that there is seldom very much salvage from the houses or mining equipment. The amortization, interest, and repairs, in the case of a first-class house, amount to more than the miner will pay.

The above are investment items, and must be paid off out of the price received for the coal. They are as much a part of the cost of a ton of coal as are the following items.

5. Supplies include pit posts, track renewals, etc., inside the mine; and power-house supplies, machine repairs, horseshoeing, purchased power, etc. The cost of supplies will vary from 5 to 20 cents per ton.

6. Labor is the big item in coal-mining, as in most other operations. Labor costs in coal-mining have been greatly affected by strikes and threats of strikes. Mining seems especially vulnerable to attack by the labor agitator. The average coal miner is able to live for a long time on next to nothing, and is willing to see his family suffer for the glorification of the walking delegate or union official, so that coal strikes have been long drawn out, and the public often wrought into sympathy for the miners by the "sob sisters" of the press and other means of propaganda. These strikes have often been accompanied by violence, as the authorities in many places have been very lax in enforcing law and order. It is not to be wondered at that the coal operators at length give up and make peace with the miners' union by agreeing to their demands and passing the extra cost on to the consumer.

The agreements between the operators' union and the miners' union worked rather well for many years, from 1900 to 1918, although there were at times gestures by impartial (?) government agencies which could understand a union of miners, but looked with suspicion upon a union of operators. This truce between the two unions lasted until the more or less business-like leaders of the miners' union were forced out by the more radical element of the miners. This overthrow of the more conservative leaders was followed by exorbitant union demands which the operators were in no position to resist, especially as an approaching election caused political pressure to be brought, as all parties were eager for the labor vote. Then, too, it was hoped to pass the extra cost on to the consumer, as before, but meanwhile there had been opened up in the non-union fields of West Virginia numerous mines which, with their smaller royalty or price of coal in the hill, smaller investments in tipples and openings, and in some cases improved mining machinery, smaller investment in

housing, a considerably smaller wage scale, with only a slightly greater freight rate, were able to undersell the union fields, and most of the mines in the Pittsburgh district had to close down. The union miners were, of course, thrown out of employment. Some chose to remain about the work, many drifted into other employment, and others migrated to the non-union fields and worked at the lower rates and made money. A little ray of sunshine for the union mines shone the last few months, when the English miners' strike made the price of coal leap up to a point where it was profitable to pay the union scale.

The whole labor situation, not only in the mines but in other lines of industry as well, is complicated by the general belief in two economic fallacies. The first is the false notion of all labor and of many who ought to know better, that any increase in wages comes wholly out of the immediate employer, be he mine operator, manufacturer or contractor. An employer faced with an increase in wages of his employees must do one of three things—raise the price of his product, go out of business, or introduce improved machinery. The latter is possible in some lines of work, especially in manufacturing. It has been done to some extent in mining, especially in undercutting and hauling, and to a limited extent in loading, but there is not the opportunity to speed up the work in mining that there is in manufacturing.

The employer may raise the price of his product as the manufacturer is able to do, and the coal operator has done it frequently in the past, but times have changed. There is a surplus of mines, and the mine operator is confronted with the third alternative of going out of business; he has done that, too.

The second economic fallacy is that government is for something else than for the protection of life and property. This fallacy is widely prevalent. The manufacturer is of the firm opinion that there should be a high protective tariff to enable him to pay high wages, and make a profit on his goods. The railroads and other public service companies insist that their rates and tariffs must be high enough to enable them to pay the high wages insisted upon by employees (backed up by the government), and they get it, as is right. There are two other basic industries that must bear the expense of these increases; namely, the producers of food, and the producers of fuel.

The farmer insists that if the government protects the manufacturers by a high tariff, and guarantees the railroads a sufficient income,

he should be recompensed in some way, but neither he nor his politician friends have as yet devised a means. Some say that he should be guaranteed a fixed price per bushel of wheat, per bale of cotton, or per unit of any other product. But, if this is done, the cost of living goes up and the industrial and railroad employees must have higher wages, hence a higher tariff and increased railroad rates, and consequently a demand for a greater bonus for the farmer, and the circle starts all over again. Meanwhile, what of the miner? He can strike and demand higher wages, which, if the operator can pass the increase on to the consumer, will be paid.

Mining and agriculture are in the same boat to some extent. There is more land under cultivation in this country than is necessary to supply its inhabitants with food. There is more coal developed than is necessary to produce fuel for the country. There are countries that are deficient in both fuel and food.

Can the farmer and the miner furnish them with food and fuel? The answer is that they can, but naturally they insist upon being paid for it. Can these other countries pay for food and fuel? Yes, if the farmer and the miner will receive other products in exchange; but if manufactured articles are shipped into this country it will hurt the industrial employee, and that is contrary to the ideas of the industrials and their political friends.

The farmer has many friends who are putting forward many panaceas for his relief—"farm loans," "bonuses," "government warehouses," "fixing of prices," "dumping of surplus products in foreign countries by government agencies," "limitation of products." Has the coal industry the same friends? Oh yes! The miner must be paid a "living wage." If his market demands only three days' work a week, then his wages should be sufficiently high to enable him to live on the labor of these three days a week.

But what of the operator? Oh, he is rich, and should buy up coal land, open and equip mines, and mine coal, whether he can sell it at a profit or not; but the operator is not in business for his health, even if it appears to be so at times.

It would seem as if the coal industry must do one of the following things:

a. Limit production by general agreement. This is legal only for labor unions and farmers' unions, but the bootlegger has shown

the government up so thoroughly the last few years that a little bootleg limitation might get by.

b. Break up the union. This would not be of great benefit as long as we have the railroad union and organized unions in other industries.

c. Unionize all the coal-mines in the country. This would be as difficult to do as to break up the unions in the northern states, and, in either case, there would be the competition between the various coal companies and districts.

What will probably happen will be a survival of the fittest; that is, the mines in the best coal, having the least overhead, the best machinery, and the most equitable freight rates will survive.

A few years ago taxes were one of the items that, while bothersome, were not one of the chief worries of the mine operator. This is rapidly changing for the worse, and taxes now constitute one of the prominent factors in the red-ink figures in the ledger.

There is probably no industry that gets less in return for its taxes than mining. The manufacturer gets fire protection. The railroads get increases in rates, the farmer gets good roads, the general public gets police protection of a sort, but all the mine operator gets out of his taxes is the privilege of paying them.

He has to furnish his own fire protection, his own police protection, and usually has to build a road into his plant if he wants one; and yet the state of Pennsylvania assesses two cents a ton on the anthracite mined.

Fire insurance is not usually a big item in the bituminous field. Compensation insurance is a considerable item. Taxes and insurance will run from four to six cents a ton.

Profits have varied greatly in the last twelve years. Before the World War a profit of 10 cents on a ton of coal mined was considered very good. There were many mines that did not make this and many that made nothing. The World War and the years immediately following were bonanza years in coal-mining. The strange part of it is that it was not the old-time operator who made the big profits. It was the rank outsider who had hardly seen a coal-mine before the war. Some of the old-timers were so canny that they sold out at the beginning of the boom, only to buy back later at greatly advanced figures. The big coal companies were not all in a position to take advantage of the bonanza prices at the beginning of the boom, because

they were tied up with long-time contracts, at comparatively nominal prices. Then, too, the fixing of prices caught them before some of these contracts had expired, and they were not in a position to ignore the government sales edicts as some of the fly-by-night concerns were able to do. One unfortunate result of the boom was to delay for many years the era of clean coal. Buying coal on a B.t.u. basis was just coming into vogue, but the war prices knocked that out for quite a while, and users who had kicked on a few extra pounds of slack in their coal in 1913 were willing to pay $8 a ton for poor slack, and glad to get it.

It may be remarked here that the high market for coal was created by the buyers; the producers had no thought of getting such prices, neither was it caused by a scarcity of coal. It was caused by a scarcity of railroad facilities.

One of the strange thnigs about government regulation of industry is the conduct of the government coal regulating bureau during the war. Given drastic power to regulate prices, etc., it chose to ignore the obvious fact that there were plenty of mines in the country, and instead of preventing the opening of new mines—which, of course, required the services of potential miners, of mining material, and above all, of railroad facilities—it actually encouraged the opening of additional mines, and especially permitted the opening of truck mines with their inefficient mining methods, and especially poor car-loading methods. It looks as if the government were afraid of the "sob sisterhood."

Much coal may have to be abandoned as being too unprofitable to mine at the present time. The following table shows roughly what the average man in this country gets for every dollar that he spends for coal:

Purchase of coal, opening up of mine, mining machinery, and housing	0.08
Mine supplies	0.03
Labor	0.24
Insurance and taxes	0.01
Operator's profit	0.03
Railroad freight	0.36
Retailing	0.25
Total	$1.00

It would seem as if the mine which can be operated mechanically, in which the overhead is not too great, and the management is efficient, will be the one to survive the next few years.

DISCUSSION

W. E. FOHL, *Chairman*:* Ordinarily the address of the retiring Chairman or President is sacrosanct, and no discussion is invited or wanted. In this case Mr. Hopkins has been kind enough to say that he would be very glad to have discussion of the paper, and he will attempt to answer any questions you may wish to ask; so you may consider the paper before you for discussion.

GRAHAM BRIGHT:† In regard to strip mining, the speaker mentioned 50 cents and $1 a ton. Is that the cost of opening the mine or equipping the mine, or is it based on the annual output in tons?

N. F. HOPKINS: That is per ton of coal in the ground.

W. E. FOHL, *Chairman*: How about the cost of equipment per ton of coal?

N. F. HOPKINS: The purchase of the land and the equipment necessary to strip and load the coal will cost from 50 cents to $1 per ton of coal to be mined. Added to this is the cost of operation, which will vary considerably with the amount and character of the overburden, the thickness of the vein, the facility with which it may be loaded, and the continuity of operation of the plant. It may be as low as 25 cents and as high as 75 cents.

W. E. FOHL: In listening to the paper I was wondering about the author's method of making cost estimates. In our office when we used to make estimates we always included an item for engineering and supervision. I listened pretty carefully and did not hear that in Mr. Hopkins's estimate.

N. F. HOPKINS: That is included in the labor cost.

*Consulting Mining Engineer, Pittsburgh.
†Consulting Engineer, Howard N. Eavenson & Associates, Pittsburgh.

W. A. Weldin:* I noticed at the hearing of the lake cargo coal rate case before the Interstate Commerce Commission that it was testified on behalf of the complainant that in a certain part of the field of a large local company, taxes and interest cost them $99 per acre every year. That is public information now. It is a rather extreme case. I think it was also testified that that particular coal was intended to be mined out in about thirty years from now, but at the present rate it would be more like 50 years, so you can figure for yourself what that coal will cost to mine.

W. E. Fohl: I noticed that Mr. Hopkins said that under the best mining methods there was a record of 85 per cent. recovery. Under the best mining methods I should like to suggest that there are many instances where the recovery is 90 per cent.

N. F. Hopkins: Then I have not seen the best. Do you know a concrete case of 90 per cent. recovery?

W. E. Fohl: Absolutely, yes. Don't I, Mr. Haworth?

M. E. Haworth:† Yes, sir.

C. H. Dodge:‡ One question has occurred to me which may merit discussion; that is, the labor question. Mr. Hopkins spoke of the hours spent underground by the coal miner as eight hours or less. In quite a few instances they have been more. During winter months men sometimes do not see daylight on a working day. Can anyone give information as to what we can do to shorten the working time to eight hours where time spent underground is considerably more?

W. E. Fohl: There is plenty of information available along that line if someone here will answer the question. There are plenty of people here who are competent to talk on that subject. Mr. Hopkins, do you care to answer the question?

N. F. Hopkins: I would rather someone else more closely connected with the operating end of the mining business would do that.

*Blum, Weldin & Co., Pittsburgh.
†Chief Engineer, Hillman Coal & Coke Co., Pittsburgh.
‡Engineer, H. C. Frick Coke Co., Scottdale, Pa.

From my knowledge of the industry I think the coal-mining industry is overmanned; that there are too many miners.

W. E. Fohl, *Chairman*: Mr. MacFarren, you have not been saying anything. Can't you tell us something of the lightening of labor in the mine, and your own efforts in that direction?

W. W. MacFarren:* I can't say very much because I have not been able to do very much.

You are all familiar with what has been done with loading machines, and, of course, with cutting machines and conveyors and other mining machinery. The only thing of which I have any special knowledge is a machine for breaking down coal hydraulically, which can be built as a breaking-down machine only, or as a cutting and breaking machine, or as a cutting, breaking, and loading machine. I built one such machine for the Pittsburgh Coal Company, and have designed a dozen others for myself which have never been built; and I expect shortly to have that principle absolutely under control by means of patents. I have been fighting the matter through the patent office for over ten years.

A machine for breaking down coal hydraulically must, like any other successful machine, be properly designed and built for the specific work it is to do. When this is done, the method offers very great operating advantages. First, all explosives are eliminated, and this effects a considerable direct saving, because the power required to push coal down is never more than 5 or 10 horse-power for less than a minute; second, the dangers due to the use of explosives are entirely eliminated; and third, better control of the physical "quality" of the coal is obtained. Coal broken by hydraulic pressure comes down in larger lumps, and always, in any size, in more solid lumps which stand handling and transportation with much less breakage than when shot down with explosives. Furthermore, the size of the lump broken down may, to a considerable extent, be controlled by the manner in which the pressure is applied. I make these statements with full knowledge gained by costly experiments and as proved facts; not merely as my opinions.

*Consulting Mechanical Engineer, Oakmont, Pa.

I was somewhat disappointed that in Mr. Hopkins's very able paper he did not go into the possible economies to be effected by improved machinery more than he did, but I see that in covering so much ground he could not do it. One other little thing, I would like to inquire into Mr. Hopkins's classification of mules as mining machinery. I have heard a mule called a good many other names, but never a machine.

N. F. Hopkins: Motors take the place of mules. You do not buy your laborers, but you do buy your motors and your mules, and I classified mules under machinery for that reason. It is part of the equipment to operate the mine.

Graham Bright: In regard to the time the miners are actually working, I am not an expert on that end of the mining game, but I do know that every time I go around a mine I find that the men go in about seven o'clock in the morning and start coming out around about noon or right after noon. As to working much more than eight hours, there may be mines where this is done, but I think you will find that the average is less than eight hours. In most cases, after they have done what they think is enough for a day, they quit, unless rules are made that force the miners to clear up the place before quitting, which ought to be done to make mining pay. In most cases the mine systems are so laid out that this can be done in an eight-hour shift without any trouble. I should say that the men are spending less time underground now than they did formerly.

In addition, the work is being made very much easier by means of mechanical appliances of various kinds. The cutting machine is so much easier than the old punching machine. It took a "he man" to operate one of those old punching machines. In regard to shoveling, the miner used to have to shovel coal into cars as high as his chin. Now you see cars not more than 20 or 30 inches high, and it is much less work to put coal into those cars than into the old high wooden cars. A further step in reducing the labor of loading is by means of conveyors which are only 18 inches high. Every place you go about the mine to-day you find provision made for lessening the actual manual labor. Things are made easier, the work is being laid out for the men, and I should say that the statement that the men are work-

ing harder and longer now is contrary to what I have seen in going about the mining regions.

N. F. Hopkins: Probably not a great many men are able to clean up their places in five or six hours. Some are able to do so, however, but this ability to do the work in let us say six hours should not mean that the little fellow should be compelled to leave his work unfinished at the end of that time, or work unduly hard in order to finish in six hours what he should take eight hours to do. It is probable that more harm has been done by strenuous efforts to finish a job quickly so that the worker may loaf or go to a picnic than has been done by any long hours that are likely to be worked now.

This does not apply to manual labor alone. If one has to walk a mile to work he would not run in order to get there in 15 minutes when he could easily walk in 20. The hours of work should be such that the maximum amount of work can be done in that time without undue or injurious exertion. Reasonably hard work and reasonably long hours probably never hurt anyone, while undue exertion, whether in work or play, may be injurious.

The miners say that if they win the six-hour day, then they will fight for the five-hour day, and then the four-hour day, and the three-hour day. It may be asked if their wives will then do their housework and cook their meals in three hours.

Graham Bright: I would like to say further on that question that the designing of the lower cars and the installation of conveyors has made more men available for loading than were available before. As Mr. Hopkins says, it took a strong man to clean up a place in six hours under the older conditions, and there were not a great many men available that could do that. The men who were not quite so strong had to take other jobs that did not pay as much. Now the companies are making it easier, and those fellows can now go in the mine and do the loading.

The question of actual strength required to do a given piece of work was brought out very forcibly to me in East Pittsburgh a few years ago. We were making eight-inch shells. They came in from various steel companies in very rough forgings and they had to be unloaded out of box-cars and placed on large drill-presses with a row

of upright rods and these shells had to be slipped down over the tops of those rods and the tops cut off. The men that put the shell on those rods got pretty high pay, possibly $15 a day. A big fellow was putting them on one of the drill-presses and a little fellow was unloading them, and he was not getting very much as compared with the big fellow. He knew what the big fellow was getting, and he kept hounding the boss to change his job and let him do that work. The boss knew he could not do it, but finally let him start at it. Everything went fine for about an hour. The crowd all around knew what was going on. Along about ten o'clock he looked as though he was slowing down a little. At half past ten he was wrapping his arms around the shells. By eleven o'clock he lay down and could not lift another one. That is an indication of what some loading jobs require. It requires a strength the average man does not have. These new improvements around coal-mines are making available a lot more men for the hard work.

C. H. Dodge: In reply to Mr. Bright, experiences and conditions vary for different localities. He brought up two questions. One was the question of the size of mine-cars. It is generally accepted that the bigger the car up to certain limits, the lower would be the cost of transportation and general day-labor work.

So far, the conveyors have generally been confined to the thinner seams and do not appear to be economical except in these seams where the high cost of brushing roof, etc., can be avoided by utilizing the conveyor.

Longer than eight hours is exceptional for the Pittsburgh district. Under certain mining methods and labor conditions these hours vary. Further south in southern Pennsylvania, West Virginia, and Kentucky nine or ten hours is not uncommon. The latter condition may be partly due to inadequate management or supervision and is also dependent on local natural conditions and mining difficulties.

Graham Bright: I think the gentleman misunderstood me. I said a low car. I did not mean a small car. The low cars hold more coal than the high cars did. The old wooden cars, though they were higher, did not hold as much coal. The low cars have more cubic capacity than the high wooden cars.

EDWARD STEIDLE:* I do not believe it is a matter of physical strength altogether as to the amount of work a miner can do; for example, a loader. Skill is an important factor. Many small men load more coal than big men. I have in mind observations made in Utah before the World War. Several mines in the Castle Gate district employed Japanese labor. Those little fellows, weighing possibly 130 pounds, would load on the average more coal than the biggest loaders of any other nationality, and do it apparently without becoming very much fatigued. Likewise, their places were kept cleaner and apparently safer. I think skill is a primary factor. We do not have many skilled loaders; that is, men who can work the coal out of the face and into the cars with minimum physical effort.

N. F. HOPKINS: Mr. MacFarren expresses disappointment at the paper not going into the possible economies to be effected by machinery. To do so would require a far longer paper than this, and might be out of date before it was printed. The writer understands that one of our members did write a book on coal-handling equipment and machinery, but before the printer can get around to set up the type the book needs revision, and so the book has never been published.

Also it will be noted that the title is "Economics" and not "Economies." "Economics," as the writer understands it, means the terms and factors forming the equation of conditions as they are. "Economies" are the new *x* terms that are to be introduced in order to produce the formula for things as they may be.

The writer hoped to bring out more discussion on one of the basic difficulties in the coal business; that is, the fact that the coal business from now on must be more or less of a world industry, competing for sales in the markets of the world, but be at the same time hampered by local impediments like the protective tariff.

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RECENT TREND IN SEWAGE DISPOSAL DEVELOPED IN DESIGN FOR FOSTORIA, OHIO*

By J. F. Laboon†

Introduction. Much has been written of the trend of present-day practice in the art of sewage disposal, the most important developments of which are so-called detritus tanks where the ever present and increasing quantities of grease from garages and industries are intercepted in conjunction with grit in the combined type of sewerage system; the separate digestion of sludge in disposal plants as contrasted to the Imhoff or two-story tank type; and the application of means for the digestion of the sludge developed in enormous quantities in the activated-sludge type of disposal plant.

The second of the important developments listed in the previous paragraph has been adopted in the design of the proposed improvements to the sewage disposal plant of the city of Fostoria, Ohio.

Separate sludge digestion is now being employed at Baltimore; Birmingham, England; Lincoln, Neb.; Plainfield, N. J.; Washington, Pa.; Butler, Pa.; Boonton, N. J.; Merchantville, N. J.; Madison, Wis.; Hartford, Wis.; Oberlin, Ohio; and Leetonia, Ohio, amongst others. Of those named, with possibly one or two exceptions, all are operated quite satisfactorily. The most notable plant is the one at Baltimore, where the Imhoff tanks, built more than ten years ago, were converted into separate sludge-digestion tanks shortly after their construction, when considerable difficulty was experienced with their operation on the Imhoff principle. None of these plants, with the exception of Plainfield, is equipped with lately developed processes of sewage-gas collection, lime treatment for hydrogen-ion correction, and heat application for sludge digestion, as have been included in the Fostoria plant design.

History of Existing Sewage Disposal Plant. Fostoria has had a sewage disposal plant since 1892. The first installation, made then, consisted of two covered septic tanks, each 100 feet long, 30 feet wide and 9 feet deep, from which settled liquor was pumped by a simple

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steam-engine-driven centrifugal pump to six sand filters having a total area of 5.6 acres. The sand filters were of a modified design, consisting of 11 inches of sand underdrained by six-inch tile pipe laid in trenches two feet wide and 3½ feet deep, 15 feet from center to center. These trenches were filled with sand. A basket screen was installed in a pit located at the junction of the outfall sewers just preceding the septic tanks. The septic tanks were abandoned in 1914, when one of these tanks was used as the foundation of an Imhoff tank installation. A new pump pit incorporating vertical motor-driven centrifugal pumps was installed at the same time, together with a wet well immediately adjoining the pump pit. The sand filters continued to function with more or less success for some years, although somewhat overloaded. In 1923, due to the wear and tear on the pumping machinery and other difficulties with the plant generally, the city employed the J. N. Chester Engineers to make an investigation of and report on the existing conditions, as the result of which the city provided $75,000 for improvement work. The improvements consisted of the rehabilitation of the pumping station; the scraping of the sand beds and the installation thereon of a distribution system; replacement of the 12-inch Vine Street intercepting sewer by a concrete and segmental-tile-block sewer ranging in size from 42 to 60 inches; the construction of intercepting and overflow works on each of the two intercepting sewers, and one branch sewer to carry off the excess storm water to the river; the construction of a combined screen and grit chamber; the reconstruction of the old basket screen chamber as a valve chamber for controlling the two intercepting sewers; the remodeling of the Imhoff tank to improve operating conditions; the installation of new automatically controlled pumping machinery, within a new brick superstructure; the enlargement of the dry-well pump pit to accommodate horizontal motor-driven centrifugal pumps which replaced the vertical ones; the installation of new suction and discharge piping between the wet well and the Imhoff tanks, respectively; the waterproofing of the old dry pump well by treatment with gunite; the restoration of the flume connecting the Imhoff tank with the sand filters by gunite treatment; the construction of a new sludge bed which doubled the sludge-bed capacity of the plant; the resurfacing of the old sludge beds; and the construction of a new outfall sewer. These improvements were completed in 1924.

The construction of the new intercepter prevented further overflow of the untreated sewage into the Portage River at the foot of Vine Street, which had been rather a regular occurrence due to the inability of the 12-inch intercepter to carry even the normal dry-weather flows at the flat grade that prevailed. An improvement in the condition of the river resulted immediately with the completion of the large intercepter, as all of the dry-weather sewage flow was then admitted to the sewage disposal plant for treatment.

It might be interesting to note that the investigation developed the fact that the sewage received at the disposal plant a portion of the time was acid in character and contained appreciable quantities of iron in the form of ferrous sulphate. The acidity had affected the concrete work to the extent that the reinforcing steel was exposed below the flow line not only in the concrete flumes, but also in the Imhoff tank and in other concrete structures that came in contact with the sewage. The pumps were deteriorating rapidly and required frequent repair. An investigation of the industries was made with a view to determining the character and quantity of trade wastes discharged into the sewer system. The cause of the acid condition was definitely determined and steps were taken to prevent its recurrence.

The industry in question was sincerely interested in correcting the acid character of its wastes and employed the J. N. Chester Engineers to recommend a manner of treatment whereby the acid discharge in the trade wastes from this plant might be neutralized. The industry installed the recommended lime process of neutralization and the sewage plant operated apparently without any signs of acid sewage for a while after the improvements to the sewage disposal plant were completed.

This condition, however, changed rather abruptly on the installation at the industrial plant of a patented process of neutralization involving the use of marl as recommended by a former state official. This process, it was said, would reduce operating costs which were being occasioned by the large quantities of lime necessarily used in the original neutralization plant. The result was that considerable damage was done to the pumping machinery and concrete work at the sewage disposal plant and to the concrete intercepting sewers installed as a part of the late improvements. These improvements to the sewage disposal plant were practically destroyed during this period of

operation. The engineers, in their 1923 report, had warned the city against just such a result. To the credit of the industry, it must be pointed out that upon discovery of the failure of the marl neutralization plant immediate steps were taken to restore and place in operation the original lime plant. To further protect against these acid wastes, and at the same time to reduce the cost of neutralization, this industry has installed a centrifugal type of iron-sulphate and spent-acid liquor recovery plant which will soon be placed in operation.

For some time the city had been threatened with lawsuits by the owners of farms located below the sewage disposal plant, who claimed pollution of the Portage River by the sewage of the city of Fostoria. These suits finally developed with the result that the local courts granted an injunction prohibiting the discharge of sewage into the Portage River. This decision was appealed from in the Supreme Court of the state, which handed down a decision on December 21, 1926, rejecting the appeal of the city of Fostoria from the judgment of the county court and restraining the city from the use of the Portage River to drain sewage from the city's disposal plant. The court announced that the city of Fostoria, in using the East Branch of the Portage River as a sewage disposal outlet, "is discharging foul, noxious and injurious deposits which are thereupon carried on or over the land of the plaintiffs, causing noxious odors, vapor and gases to be cast in and upon the premises of the plaintiffs."

The decision is somewhat unique in character and the case will be followed closely by engineers and others interested in sanitary engineering. The results of an injunction of this kind being served against any community need not be gone into in detail here to develop their extreme consequences.

The city, upon the impairment of the 1923 improvements, again employed the J. N. Chester Engineers to recommend and design such improvements to the sewage disposal plant as would not only relieve the conditions now existent in the river below the sewage disposal plant outfall, but also modernize and improve the sewage disposal plant so that the resulting effluent might be of a high character consistent with simplicity and positiveness of operation. In a further investigation of the conditions now existent at the sewage disposal plant and of the character of the river below the plant it was developed that the storm overflow from the largest sewer in the city

carried, at times, a waste product from one of the industrial plants which settled out in some parts of the sewerage system, but which, however, was inoffensive and in its simplest form, inasmuch as it was elementary carbon. This black deposit has undoubtedly been mistaken for the product of sewage decomposition. The industry in question has used, for a number of years, several settling basins which settle out the great majority of the carbon deposit from the plant effluent, but there is undoubtedly a certain proportion of this material which is carried over into the sewers and in time builds up deposits.

Proposed Improvements. The engineers designed a separate sludge-digestion system of sewage disposal after having given consideration to the several practical types applicable to the conditions at Fostoria. Two types of sewage disposal plant offered the best solution, economically and from the standpoint of practical and successful operation. These were (1) Imhoff tanks with trickling filters; and (2) separate sludge digestion with trickling filters. Either would serve well. Cost studies showed that an Imhoff-tank plant with trickling filters incorporating the existing Imhoff tank as part of the new plant would cost $240,000, whereas a separate sludge-digestion system of disposal, using the existing Imhoff tank as a sludge-digestion tank, upon remodeling, would cost $210,000. The substitution of trickling filters for sand filters became necessary from the standpoint of economics, as the sand beds would have had to be completely reconstructed to conform to modern practice, and a three-foot depth of sand, instead of 11 inches as now constructed, would be required. This would have involved a cost far greater than will be the case with trickling filters. The existing sand beds, therefore, are to be abandoned. The elevation of the existing Imhoff tank would not permit the installation of a trickling filter of an optimum depth, followed by humus tanks without additional pumping; furthermore, any increased depth of structures underground would increase the cost materially by virtue of the underlying stratum of rock located a few feet below the ground surface. It would have been necessary in the use of an Imhoff tank design to raise the existing Imhoff tank at least four feet, which would require a general strengthening of the tank to withstand the additional head of water placed upon it, as the tank was already in a weakened condition. With separate sludge diges-

tion the existing Imhoff tank can be utilized in its present condition without increasing the height of its walls, and to complete the system it is necessary only to construct the clarifier tanks at an elevation sufficient to give proper fall to the trickling filter and humus tanks, and to permit the discharge of sludge from the clarifier tanks into the separate sludge-digestion tank by gravity. The simplicity of adaptation of the existing plant and the lesser cost involved pointed to the adoption of the separate sludge-digestion scheme of disposal.

It has been said that the separate sludge-digestion system of disposal presents problems requiring more technical supervision and operation than is the case with the Imhoff-tank type of disposal, but after practical experience with the operation of Imhoff tanks and observation and personal study of separate sludge-digestion plants this statement may be made in its reversed form—that the separate sludge-digestion system of disposal makes it possible to give more technical supervision and operation and is, therefore, amenable to more intelligent operation; bearing in mind that digestion of sludge and a satisfactory effluent are the prime functions of a sewage disposal plant, but that these operations shall be performed with a minimum of odors.

The new improvements consist of:

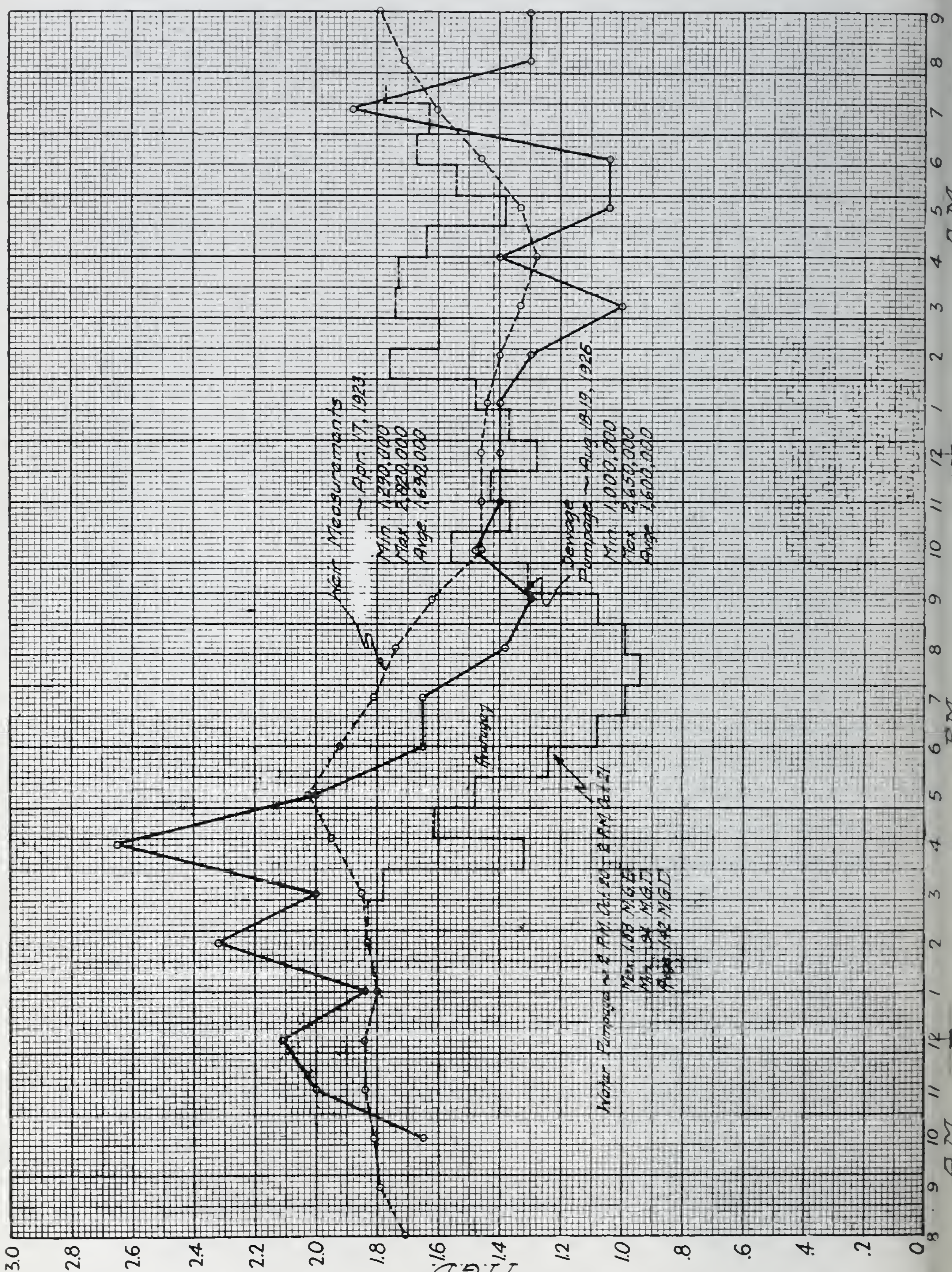
1. The installation of grit-handling apparatus.
2. A high-water alarm.
3. New vertical pumps and motors to replace the horizontal units.
4. The construction of an addition to the existing pumping station to house a chemical and bacteriological laboratory, toilet and locker room, and lime-feed devices.
5. The transformation of the existing water-pump house into a tool house.
6. The transformation of the existing Imhoff tank into a separate sludge-digestion tank.
7. The construction of sewage thickeners or clarifiers.
8. Dosing tanks.
9. Trickling filter.
10. Humus tanks.
11. New outfall sewer.

12. Resurfacing and reconstruction of existing sludge beds or the construction of a glass-covered sludge bed as an alternate.
13. Roads and walks.
14. Water line and gas line connecting to existing utilities in the city.
15. The provision of a complete outfit of tools and operating equipment.

Population. According to the city directory of 1925, the best source of information available, Fostoria has a population slightly under 12,000, with every indication of a healthy growth by virtue of the industrial character of the city and particularly because of the extensive industrial developments now in progress. The area of the city within the corporate limits is 4.2 square miles. Five main-line railroads enter the city.

Quantity of Sewage. To develop the present quantity of sewage flow, an accurate record was kept of the time and number of pumpages, and the time cycle of each pumpage for a 24-hour period beginning at 9 a.m., August 18, and ending at 9:13 a.m., August 19, 1926. From these data, having observed the output of the pump in gallons per minute, it was possible to determine the total sewage flow and its variation over the 24-hour period. The developed curve indicates a minimum flow of 1,000,000 gallons a day, a maximum of 2,650,000 gallons a day, and an average of 1,600,000 gallons, or approximately 133 gallons per capita as a dry-weather measure, as indicated in Fig. 1. The hourly pumpage at the water-works for October 20-21, 1926, is shown in the same diagram for the purpose of comparison of the two curves. The period immediately preceding the 24-hour sewage measurement was fairly dry and the statement that these results were found under dry-weather conditions is supported by a comparison of these data with the weir measurements made April 17, 1923, during a wet period in the spring, the results of which are shown also in Fig. 1. The weir measurements of 1923 gave an average per capita flow of 169 gallons.

Character of Sewage. A composite sample of sewage was collected over a 24-hour period at each fifth pumping-cycle period, rep-


Weir Measurements ~ Apr. 17, 1923.
Min. 1,290,000
Avge. 1,690,000
Sewage Pumpage ~ Aug. 18-19, 1926.
Min. 1,000,000
Max. 2,650,000
Avge. 1,600,000
Average
M.G.D.
A.M.
P.M.

resenting approximately 15-minute intervals. These samples were taken simultaneously with the observations for quantity of sewage on August 18-19. The results of the chemical analysis of the composite sample follows. Due to the failure to add chloroform to the sample when collecting, nitrogen and ammonias could not be determined.

	Parts per million
Total solids	1650
Suspended solids	350
Chlorids	80
Oxygen consumed	47
Dissolved oxygen	0
Alkalinity to methyl orange	130
Total iron (mostly ferrous)	70

The acid nature of the sewage experienced at times has already been discussed. It is evident from the above analysis that the neutralizing plant at the wire mills was in effective operation, although a large amount of iron found its way into the city sewers.

Capacity of Plant. The new improvements have been designed with a view to treating sewage from a population of 15,000, which will permit of more than 25 per cent. growth in the present population. The sewage flow has been taken as 133 gallons per capita as revealed by the measurements of August 18-19, 1926; and the minimum and maximum flows of the new design are based on the results of these measurements. The design flows are:

Minimum, 1,250,000 gallons a day
Maximum, 3,310,000 gallons a day
Average, 2,000,000 gallons a day

Grit-Handling Apparatus. Over the grit chamber is to be erected a monorail system for carrying an electric hoist operating a 3/8 cubic yard grab bucket by means of which the intercepted grit will be removed from either channel and loaded into carts or trucks at the end of the grit chamber. Lighting fixtures are being installed over the grit chamber for the convenience of the operator at night.

High-Water Alarm. A high-water alarm of the float type is to be installed in the screen compartment of the grit chamber to warn

the operators of an abnormal sewage flow such as would be experienced in case of rain and to warn of a rise in the sewage ahead of the screens due to the failure to remove screenings, in either of which cases the operator's attention would be called to the necessity of investigation. Should the rise be due to rainfall and the pumps be unable to handle the sewage flow, the station would then be shut down until the flow to the sewage plant became sufficiently reduced to permit of resumption of operations.

Pumps. The dry pump pit has been flooded on a number of occasions with consequent damage to the motors. It is proposed to install two pumps—one of 2,500,000 and one of 3,500,000 gallons per day capacity. These are to be vertical motor-driven centrifugal pumps with motors located above the level of the operating floor. These pumps are to be of the Wood-Trash, Yeoman, Hayton, Buffalo or similar type, with impellers designed so that balls of diameter practically equivalent to that of the discharge pipe may pass through unobstructed. The pumps will be operated automatically by means of float switches. These switches will be arranged to control the speed of the motors, depending upon the height of sewage in the wet well. There will be four float switches serving either pump, regulating the speed at four points, namely, 80, 87, 93 and 100 per cent. The purpose is to obtain as nearly constant flow of sewage through the plant as is practical, as this will be conducive to the best results.

Laboratories, Etc. A laboratory equipped with apparatus for making ordinary sewage analyses is incorporated as a part of the addition to the existing sewage pumping station building. This addition will also include a locker room, toilet room, and a room where a machine for dry feeding of lime will be installed, with space for the storage of lime. A basement is being constructed under the lime-feed room for the accommodation of the heating plant and sewage-gas apparatus.

Tool House. The existing water-pump house will be transformed into a tool house where shovels and such tools will be kept.

Separate Sludge-Digestion Tank. The existing Imhoff tank will be remodeled in such a way as to serve as a separate sludge-digestion

tank. Part of the existing concrete baffles will be removed, thus eliminating the sedimentation compartment of the old Imhoff tank. A valved sludge pipe is being installed for each of the three hopper bottoms, whereby sludge may be distributed as desired. At the bottom of the tanks is being installed a new water-agitating system consisting of perforated, two-inch, wrought-iron pipe to replace the lead pipes which were removed without warrant when the improvements were made in 1923. A system of heating coils of 1¼-inch, wrought-iron pipe is being installed in the tank for the application of heat to the digesting sludge, thus shortening the period of digestion in case it becomes desirable to do so during the winter months when sludge may be allowed to accumulate due to undesirable drying conditions. The heater, which will serve both the sludge-digestion compartment and the heating of the buildings, will be arranged to use gas to be collected from the separate sludge-digestion tank. A partially submerged concrete roof is to be installed over the entire surface of the tank for several purposes, among which are the prevention of odors, the submersion of scum, the collection of gases and the insulation of the sewage against cold. Three gas-collecting tanks of galvanized iron are to be installed in the concrete cover for the purpose of collecting sewage gases. These tanks are connected to the piping leading to the gas scrubber located in the lime-feed room, and are further connected to the gas-storage tank supplying the heater. The sludge will be fed from the thickeners into the separate sludge-digestion tank by gravity, and the displaced liquid will flow out through a swinging outlet pipe which discharges into the sewage well. A dry lime-feed machine has been added to the equipment in the extension of the pump-station building. The purpose of this machine will be to feed lime into the sludge line leading from the thickener to the separate sludge-digestion tank, in order that the optimum hydrogen-ion concentration of the sludge may be maintained with the resulting elimination of acid digestion. A water ejector will be used for feeding the lime into the sludge line under pressure. Mixing between the lime and sludge will be accomplished in the remaining travel through the sludge pipe. The capacity of the remodeled tank is 60,000 cubic feet, or four cubic feet per capita, but all of this will hardly be available as actual sludge capacity.

The design of the several features of the separate digestion of sludge has been based on experiments conducted by Dr. Rudolfs at the New Jersey Sewage Experiment Station as substantially confirmed by Mr. Baity in his research work at Harvard Engineering School and as applied in a practical way by John R. Downes, superintendent of the sewage disposal plant at Plainfield, N. J. The substantial developments are with respect to the control of the character of sludge digestion by means of the hydrogen-ion concentration; the acceleration of digestion by the application of the heat; and the maintenance of anaërobic digestion of sludge. Generally speaking, it may be said that research work has developed optimum pH values of 7.3 to 7.6 and temperatures of 78 to 80 degrees F. The character and quantity of production of gas may be governed by the control of pH and temperature. The gas must be washed of its CO_2 to develop its best combustible qualities, and a scrubber for washing out the CO_2 is therefore provided for this purpose. It is hoped that sufficient gas will be produced to furnish the heat necessary to maintain optimum temperatures throughout the year and leave a surplus for other purposes.

Settling Tanks and Sewage Thickeners. Two sewage thickeners of the Dorr and Link-Belt type have been designed for use in the settling tanks with a view to obtaining bids on both types. Both lay-outs have a detention capacity of two hours at average design flow. These tanks are to be fully equipped with an economical type of sewage thickener. The difference in head between the thickeners and the separate sludge-digestion tank is 4.33 feet. The flow of the thickened sewage will be controlled by means of hand-operated gate-valves. Sampling pipes discharging into open sewers leading to the wet well are provided for each sludge pipe, so that the character of the thickened sludge may be inspected during the discharge of the sludge to the sludge-digestion tank. The tanks of the Dorr type are each 30 feet square and 12 feet, 6 inches deep; while those of the Link-Belt type are each 18 feet wide, 50 feet long, and 13 feet deep. It is proposed to remove sludge twice daily. The Link-Belt scraper type would operate about 30 minutes daily, while the Dorr thickeners, if installed, would operate as required. The Link-Belt type will present the added feature of having the return flight of the scraper oper-

ate at the surface of the sewage tank so as to skim off the floating matter, particularly grease.

Dosing Tanks. Two dosing tanks are to be built, equipped with 20-inch siphons of the type known as No. 2, manufactured by the Pacific Flush Tank Company. Each tank has a capacity of 8300 gallons. A six-foot automatic air-lock feed is provided with each tank. The computed losses are as follows:

Feed	8 inches
Weir	8 inches
Distribution	8 inches

The operating cycles are computed to be as follows:

	Millions of gallons a day	Discharge minutes	Resting minutes
At capacity of larger pump	3.5	2½	0.9
At design average flow	2	2½	3.5
At design minimum flow	1.25	2½	7
At design maximum flow	3.3	2½	1
At present average flow	1.6	2½	5
At present minimum flow	1	2½	9.5

An overflow weir and by-pass sluice gate have been provided integral with the sewage-inlet channel, primarily so that sewage may be by-passed around the dosing tanks and the trickling filter in the winter, if found advisable. The dosing tanks are to be located in the existing sand filters just above the proposed trickling filter.

Trickling Filter. The trickling filter is rated at 2500 people per acre per foot depth, and on the basis of an average depth of seven feet and a population of 15,000 people the area becomes six-sevenths of an acre. The trickling filter as designed has surface dimensions of 188 feet, 3 inches, by 190 feet; while the dimensions at the bottom are 183 feet, 9 inches, and 185 feet, 6 inches. The sewage will be distributed through a single cast-iron distributing main laid at the surface of the bed, from which six-inch, cast-iron laterals will branch off on both sides. The filter stone, as specified, is to consist of suitable

limestone ranging in size from 1½ to 2½ inches. It is proposed to use 246 full nozzles and 18 half nozzles of either the latest improved ⅞-inch Taylor type, or the 13/16-inch Worcester type. The maximum net head is six feet. These nozzles are spaced 12.25 feet from center to center, measured along the sides of an isosceles triangle. The underdrainage system is patterned somewhat after the Fitchburg type, and bids will be requested on four alternates of substantially the same design, differing only in the method of installation. Two main drainage gutters terminate in 18-inch terra-cotta mains leading to the humus tanks. Bids will be requested on waterproofing the tops of the walls and the sides one foot down from the top around the four sides of the trickling filter.

Humus Tanks. Two humus tanks are being provided, with a combined capacity of 1½ hours at normal flow. Hydraulic plug valves are being provided at each of the drain outlets. A control manhole is located at the end of the tanks. A 10-inch, terra-cotta drain leads from the humus tank to the raw sewage pump well. This becomes necessary to save pumping, as the bottom is too low to drain into the river. The tops of the walls are designed at elevation 854.25, which is approximately two feet lower than the local high-water record. These tanks will be flooded at high water, but no harm can be done except the settling out in the tanks of some mud from the flood waters, and no backing up into the trickling filter will be possible if the operators take the precaution to close the gates on the inflow lines entering the humus tanks. Designs have been made for tanks accommodating Dorr and Link-Belt thickening equipment, so that daily removal of the accumulated sludge may be accomplished. It is well known that the accumulation of sludge in humus tanks is a common source of vile odors to be found at sewage disposal plants, and it is with the purpose in mind to avoid such a condition that daily removal of this sludge is desired. It is agreed that the detention period of the humus tanks may be reduced to one hour with the installation of thickening equipment, in contrast to the period of 1½ hours required with plain settling tanks. Bids will be received on the plain tanks, on the Dorr thickeners, and on the Link-Belt thickeners, and contracts will be let on the basis of the funds available for the purpose.

New Outfall Sewer. A new outfall sewer has been designed to discharge from the humus tanks into the Portage River about 100 feet distant. A concrete abutment is being installed at the river end. The old outfall sewer will be used during the winter at such periods as the trickling filter is being by-passed.

Reconstruction of Existing Sludge Beds. All of the existing sludge beds will be resurfaced to the extent of replacing the three-inch layer of sand with five inches of sand. Sludge carriers of the manure carrier type are to be installed in pairs over each sludge bed. These will be sufficiently high to permit dumping into a cart or truck at the end of the beds. The unloading end of the trolley will be lower to relieve the burden of pushing the loaded carrier. The drains in sludge beds 3 and 4 will be reconstructed to drain into the 10-inch, terra-cotta drain leading to the raw sewage well, as these beds are now back flooded during high waters. This reconstruction will prevent such back flooding. The concrete trough leading from the existing Imhoff tank to old sludge beds 1 and 2 will be replaced by an underground sludge pipe leading to the existing distribution chamber. The existing concrete trough will be destroyed and removed.

An alternate to the above work consists in a design of a glass cover over sludge bed No. 4 involving an area of 5600 square feet. Should the city funds and the nature of the competitive bids justify it, the cover over sludge bed No. 4 and the reconstruction of the bed will be undertaken in preference to the reconstruction of all of the open beds. The adjoining sludge bed, No. 3, will be left intact for future use and development as found necessary, while the old sludge beds 1 and 2 will be destroyed, as there will be no occasion for their use for a great many years to come, if ever.

The total area of the sludge beds now existent is 20,000 square feet, which is equivalent to 1.74 feet per capita on the basis of the existing population of approximately 11,500, and 1.33 square feet on the design basis of 15,000. For future extension, existing sludge bed No. 3 may be reconstructed and used as an open bed, or a cover may be erected over it, thus permitting of doubling the capacity.

Roads and Walks. New roads and walks will be built throughout the plant and the entire grounds will be seeded and made presentable.

Water and Gas Lines. A four-inch water line and a two-inch gas line are to be constructed from County Line Street at Union Court to the sewage disposal plant, to provide water for all general purposes and gas for use in the laboratories and for heating when necessary. The water-line improvement was contemplated in the original plans for the improvement of the sewage disposal plant designed by the writer's firm in 1923, but the bids on this item were rejected and the existing water pump was reinstalled to supply water from the outfall sewer.

Estimated Cost. The cost of the improvements is estimated at $200,000. These funds are to be provided through special legislation of the emergency order, as provided for by statute. In the state of Ohio, it is possible to issue bonds in the sum of three per cent. of the assessed valuation for any sanitary improvements ordered by the State Department of Health, without the necessity of submitting the question to referendum. The enabling act has been of great value to the people in obtaining required improvements to the waterworks and sewerage systems throughout the state. Another act of great value to municipalities in the state of Ohio is the one recently passed by the state legislature permitting the collection of sewer rentals in the same manner as revenues for the use of water supplied by the waterworks, thus making a direct assessment against those benefited by the sewerage system. The revenues collected from such rentals may be used in defraying the expenses of operation of both the sewerage and sewage disposal systems of the municipality. The approval of the plans and specifications of the Fostoria improvements are predicated on the city's instituting the sewer-rental measure and the provision of technical operation of the sewage works.

Bids on the improvements outlined herein are to be taken immediately upon the completion of the legislation now in progress providing the funds necessary for the work.

DISCUSSION

Nathan B. Jacobs:* Experience in our Cleveland office, of which Mr. Charles L. Crosier is manager, suggests that additional data on the history of the Fostoria plant may be of interest.

It is very fine to have a paper of this kind, not along strictly academic lines, but taking a plant as an object and taking us through the whole study of the development. To our knowledge, this is the first paper before this Society that has treated of a sewage disposal plant and given a complete description not only of the new development but of the history of the plant and some of the vicissitudes which are typical in the development of the sewage disposal industry, if we may call it that. The description of the Fostoria plant is probably typical of a great many of the plants throughout Ohio. They started twenty-five or thirty years ago to develop sewage disposal and they have mostly gone the way of the Fostoria plant. This can probably be traced to design, and to the theory that the plant should be as simple as possible so that it would practically operate itself, because it was felt that there was going to be no competent supervision, and the plants were erected on that basis.

Sewage disposal is now undergoing a revolution. The development of colloidal chemistry in the last few years has revolutionized both the theory and design of sewage disposal. It is fine to have brought before the Society one of the first examples of the use of colloidal chemistry in the development of design for a town of this size. That brings up a really important phase of the paper—that the plant is designed to require the service of an expert operator and to get away from the idea that the sewage disposal job should be merely a job for an ordinary laborer. The change in design of plant, requiring continually a colloidal chemist on the job and expert supervision, will mean a great deal for the sewage disposal field, and particularly in Ohio, which is one of the states that has developed a great many sewage disposal plants that have not been satisfactory. This is true not alone of Ohio; plants in this region are not giving the satisfaction they should.

A few additional data upon the history of the Fostoria plant may be of interest. The Fostoria plant was one of the earliest of the Ohio disposal works, being installed in 1896. The original plant appar-

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ently operated in a satisfactory manner for a while, but, according to the 1913 annual report of the Ohio State Board of Health, "Continued development of the city and inattention to the proper operation of the plant resulted in its deterioration and in a recurrence of the pollution of Portage Creek." This report also stated that in 1908 a complaint was submitted and investigation showed that the plant was not efficiently treating the sewage from the city. This situation continued until in 1912 an order was issued by the Governor and the Attorney General of Ohio providing that plans should be prepared and construction completed prior to July 23, 1913. Studies were undertaken and it was suggested by Mr. R. Winthrop Pratt, acting in a consulting capacity to the City Engineer of Fostoria, that secondary works consisting of sprinkling filters be provided. However, prior to the submission of the plans to the State Board of Health, changes were made so that the proposed improvements comprised the construction of grit chambers; the reconstruction of the storage basins, to serve as plain sedimentation tanks; the installation of improved pumping machinery for dosing the filters; the provision of improved facilities for removing the sludge from the tanks; filters for the drainage and drying of the sludge; and an additional area for the final treatment. This plant was proposed to have a capacity of 1,200,000 gallons a day which, it was believed, would be sufficient for a population of 12,000.

These improvements were not made, however, for in 1914 the city submitted revised plans to the State Board of Health. These plans provided for a screen chamber; a pump-well and pumping equipment; remodeling of one of the existing tanks, so that it may be used as a two-story settling tank; the installation of sludge beds; and the general improvement of the intermittent sand filters. The important change made by these plans provided for the installation of a two-story tank in place of one of the old sedimentation basins, and the elimination of the grit chamber. The sewage flow at that time was estimated at approximately 625,000 gallons a day and the plant was designed for 900,000 gallons a day. The sludge compartment capacity in the two-story tank was proposed to be 17,550 cubic feet, providing a storage for a period of 175 days. The filters were proposed to operate at a rate of 160,000 gallons per acre per day.

Operating difficulties apparently continued and resulted in the investigation and construction of 1923, as outlined in the paper. Con-

ditions evidently were temporarily improved, but further inattention to operation resulted in considerable damage to this construction and caused the development of the new plant upon which the paper is based.

The 1913 report of the State Board of Health pointed out that,

> "A factor of importance in the deterioration of the plant is the large volume of manufacturing wastes discharged into the sewers. These consist of pickling liquors from iron mills and sludge from a railroad water softening plant. Various investigations of the State Board of Health have shown that these wastes are very detrimental to the sewage treatment plant."

In spite of this knowledge, however, such conditions apparently continued. These were brought to public notice again by the investigations of 1923 as mentioned in the paper. Even then, unsatisfactory conditions followed until the 1926 investigation.

The important point indicated by these facts is the great importance of careful supervision and operation of a sewage disposal plant. The need is not only to secure a return upon the investment by satisfactory operating results, but to prevent the financial loss to the community resulting from the need of replacing work, and in defending lawsuits and paying damage claims.

Similar conditions have been found at several plants which we have recently examined, and no doubt are the common experience of most investigators. Lack of attention to operation has resulted in tanks becoming overloaded with solid matter, and either in clogging of secondary works or failure to remove the pollution from the stream into which the effluent is discharged. An interesting example of such an instance was recently noticed in a sewage disposal plant where the nozzles of the sprinkling filter were clogged up with chewing-gum. An investigation showed that the settling tanks had not been cleaned out for a long time and were almost completely filled up with solid matter.

The method of disposal adopted for Fostoria is one which, although not yet having been proved to be satisfactory for a small plant by successful operation for a long period of time, is nevertheless apparently well founded upon experimental data and upon good results for a short time with a few plants. The success of this plant, as for all others of like character, will be dependent upon the quality of supervision which the operation receives. It introduces an addi-

tional step over that required in the use of Imhoff tanks, and considerable additional mechanical equipment. Wtihout expert supervision it is thus likely to experience difficulty.

It will be interesting to know the estimated cost of operation of this proposed plant in comparison with operating an Imhoff-tank plant; also how the quality of the effluent from this plant is expected to compare with that from the Imhoff-tank plant.

It is worthy of comment that the city of Fostoria is taking advantage of the two Ohio enabling acts in financing this construction. The fact that the city has been able to secure an order of the State Board of Health is an indication that the improvements were much needed, for the usual policy of the state officials has been to issue such orders only when they have been absolutely necessary to safeguard public health. The act permitting the collection of sewer rentals offers a very convenient means of financing the operation, maintenance, and control of sewerage systems and sewage disposal works. The law provides that any surplus in this fund may be used for the enlargement or replacement of sewerage system and sewage pumping and disposal works, but may not be used for the extension of a sewerage system to serve unsewered areas or for any other purpose whatsoever. In this manner the maintenance and operation of the sewage system and disposal work are placed on the same basis as that of a water-supply system. This should do much to rehabilitate many sewage disposal systems in the state of Ohio which have fallen more or less into a state of disuse.

J. F. Laboon: In answer to Mr. Jacobs's remarks that this method of disposal has not been proved to be satisfactory for a small plant for a long period of time, I would say that there are now about forty disposal plants, mostly small, operating as separate sludge-digestion plants, and there are several singular instances of proved success. If 10 years is long enough, Washington, Pa., a small plant, has been operating on this method for at least 10 years with marked success. Baltimore, a large plant, has been operating for more than 10 years; likewise Birmingham, England, amongst others, small and large. Fixed charges and operating expenses at Fostoria will be less with this method than with Imhoff tanks. But, unlike other activities in the engineering field, it is not wholly a question of operating costs, but one of obtaining results, and any method which will not produce

good results without painful effort, regardless of how simple and cheap as to operation it may be, it is not worthy of its installation.

R. P. Forsberg, *Chairman*:* Why is it that Ohio is so far ahead of other states?

J. F. Laboon: It is one of the most active state departments of health in the United States to-day. The reason for Ohio's greater activity in sewage disposal is that the state is very flat and drainage is difficult; consequently, streams are small and thread their way through highly populated districts, and Ohio is just full of small towns and communities. I believe it is just a matter of necessity. So many domestic water-supplies are taken from these water-sheds that it is necessary to purify the sewage.

Philip S. Wickerham:† I want first to compliment the author on his treatment of subjects of such timely interest. He has covered a field in one evening which could be distributed over a week's time. Four cardinal points are cited toward which sewage disposal design is developing at the present time: (1) use of artificial heat to speed up digestion; (2) pH control; (3) the case of covered as against open sludge beds; and (4) increased operating control of the digestion process. On each of these points we might profitably have a paper and give an evening to the discussion without exhausting the subject.

I would like to ask, in connection with the artificial heat, on what basis was the plant designed; how many calories are introduced, or what method was used to compute the B.t.u.'s required to raise and maintain sludge temperatures of 70 or 80 degrees?

J. F. Laboon: The winter time will offer the greatest difficulty. Average sewage will have a temperature in the winter time of 49 or 50 degrees. Since optimum is 78 to 80 degrees, some 20 to 30 degrees of deficiency must be made up by the heating plant. A practical temperature will be around 70 degrees. I visited the Plainfield, N. J., sewage disposal plant recently, spending several days with Mr. Downes, the superintendent, who showed me some observations he had

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†Civil Engineer, Butler, Pa.

made with regard to sludge heating requirements. Mr. Downes found he could maintain temperatures of sludge with little heat. When once attained it is a simple matter to maintain temperatures. In computing the heat requirements at this particular plant, we allowed for heating the capacity of the separate sludge-digestion tanks, and for the heat losses in the concrete bottom, sides, and roof, so we have what we believe is a fair assumption of heat losses to be made up by the heating plant.

PHILIP S. WICKERHAM: Did you employ the coefficients of loss used by the American Society of Heating and Ventilating Engineers?

J. F. LABOON: Yes, practically so.

PHILIP S. WICKERHAM: With regard to the sludge mean temperature of 50 degrees used in design, it will be interesting to learn how the actual temperatures during operation compare with this assumption, and if a recording thermometer is installed their tabulation will furnish a valued and needed contribution to the profession. Mr. Charles H. Young, of the Pennsylvania Department of Health, made some extremely interesting observations a year or two ago in connection with a plant at Grove City, Pa., and found, during a period covering several winter and spring months, temperatures as low as 38 and 40 degrees. He also made some experiments on heat radiation through a liquid medium to determine the rate of heat transfer. I have not yet learned his results. Reliable data along this line are meager and I would suggest that engineers installing heating units in their designs make provision for obtaining reliable records of temperature changes occurring during actual operation, for use of the profession. This matter of heating sludge is one of the live issues in present design. Used in connection with pH control, no other single factor offers greater promise for design economy, but a too optimistic view of results to be obtained may retard its acceptance as standard practice. Personally, I am inclined to believe that, when used in connection with separate digestion, it will be found necessary in this climate to construct protective embankments to the top of all exposed tank walls and to provide top covering, to obtain effective results. I would also like to ask at what zone in the digestion tanks the heat is introduced.

J. F. LABOON: Half way on the inclined bottom slope.

PHILIP S. WICKERHAM: You use 1¼-inch pipe?

J. F. LABOON: Yes.

PHILIP S. WICKERHAM: What medium is used to introduce the heat?

J. F. LABOON: Hot water.

PHILIP S. WICKERHAM: Is positive force-feed circulation used, or thermal?

J. F. LABOON: A force-pump.

PHILIP S. WICKERHAM: Have you provisions for mixing the sludge or transferring sludge from one digester to another?

J. F. LABOON: No, we do not. We have arranged, however, to transfer sludge from the clarifiers to any one of the three hoppers of the digestion tank. After the process of digestion has begun, no attempt will be made to stir the sludge. It is pretty well established that if you mix two parts of fresh sludge with 100 parts of digested sludge on a dry basis, the sludge-digestion balance will not be disturbed.

PHILIP S. WICKERHAM: Sharon, Pa., and Butler, Pa., provide for interchange of sludge from one hopper to another, or turning over of sludge in individual hoppers. Should one hopper be sluggish, the operator has facilities for withdrawing good sludge from any desired hopper and transferring it to the hopper that is sluggish. This also furnishes additional means for pH control.

There is an additional feature regarding glass-covered drying beds. You mentioned their economy in that smaller areas are required. Another factor of importance is the ability to use covered beds to 100 per cent. capacity the year around. This not only means that a smaller area is required, but also that digestion capacity is increased, since, with open beds, ripe sludge can not be withdrawn at any and all times, due to weather conditions. With covered beds, sludge may be withdrawn at any time, to bed capacity, thereby affording additional space for fresh solids, and at the same time assisting in pH control by

permitting discharge of relatively small quantities of ripe sludge at more frequent intervals. With open beds, the operator is compelled during inclement weather to use a portion of tank space for storage instead of digestion.

J. F. LABOON: Regarding the digestion of sludge as between the different compartments of the tank, improper digestion may be eliminated by regulating the pH concentration. Instead of having compartments that will not operate equally well, it is expected to obtain uniform digestion throughout by controlling the pH factor and thus eliminate all acid digestion, which has been the most serious difficulty in the operation of most plants where positive control of sludge digestion is not to be had.

In the matter of sludge beds, my statement was predicated on winter usage, such as you point out. It is self-evident that you can not make a sludge bed treat more sludge than can be dried on it, and it is only because drying in covered beds can be accomplished the year around that covered sludge beds can be rated higher per unit area than open beds.

PHILIP S. WICKERHAM: What I wanted to stress is that while you are able to use less drying-bed surface, you are also increasing the efficiency of the digestion tanks.

J. F. LABOON: The application of heat reduces the digestion period from six months to two or three and thus you have more complete control of the sludge situation than is practical with limited sludge-bed area. In other words, winter drying of sludge could be dispensed with by reducing the time necessary to digest the sludge in the tank, which makes available additional storage facilities for the digested material.

PHILIP S. WICKERHAM: Regarding pH control, I believe another speaker mentioned the necessity of employing a chemist. Do you not think it is more desirable that the profession perfect a simplified method of determining this pH which will enable the operator to calculate the correct quantity of lime to make the adjustment? In small municipalities it is difficult to secure annual appropriations for

even the inadequate maintenance most plants receive. Efforts of the engineering profession to educate the public to a higher plane of plant maintenance are being well received and making progress as regards regular and full-time attendants, but requests for funds not absolutely essential may retard this progress. Will it not be better to advocate retention by the municipality of a consultant, preferably the designing engineer, to advise and assist the operator periodically or when needed?

J. F. Laboon: The pH determination has been somewhat simplified and there is an apparatus now marketed for that purpose, but even this apparatus is not entirely consistent in its results.

Philip S. Wickerham: I believe the work of the Pennsylvania Department of Health can not very well be excelled.

J. F. Laboon: You are making a comparison of qualities. I made a comparison simply of activities. My statement was predicated somewhat upon the legislation which the Ohio Department of Health has at hand to compel sanitary improvements. Any legislation the Department of Health needs is promptly enacted by the legislature. I dare say you will search a long time before you find a similar situation anywhere else in the United States. It is not that one state department excels another; it is a matter of the tools they have at hand with which to work. The Ohio Department of Health has been able to back up its work by virtue of the favorable legislation.

Philip S. Wickerham: That clears up the question entirely. I am glad you made that statement. My understanding is that the Ohio law has had teeth put in it only within the last few years.

J. F. Laboon: In connection with the sand filter, it would have required nearly double the present capacity of the sand beds to furnish a satisfactory effluent. The beds now are only 11 inches deep, whereas the proper design would require a depth of three feet. The sand beds therefore can not give a satisfactory effluent in their present condition, and to provide more than double the present sand-bed capacity of the plant would involve an enormous cost, far in excess of that of a trickling filter installation. It is admitted that the effluent from the sand beds will be better than that from the trickling filter, but the

fixed charges and operating cost of the trickling filter are much less than those of sand beds.

As to the contact beds, they would be used by our firm as a matter of last resort. Contact beds do not consistently furnish a satisfactory effluent, and must be kept up to maximum efficiency to furnish an effluent which might be termed satisfactory. Their maintenance and upkeep are in excess of trickling filters, generally speaking. There are fundamental theories in connection with both types which I believe would favor the trickling filter, and, furthermore, the Ohio Department of Health will not allow contact beds where trickling filters can be installed.

In the matter of chlorination, it is in use only under exceptional situations such as where you have bathing or shell-fisheries or the use of a small stream for water-supply, not far below the outfall sewer. Chlorination is an economic waste unless conditions require it. In this particular case the river is not over 15 feet wide and goes practically dry in the summer time. It is not used except for watering cattle and as a natural drainage course.

The high depreciation of the pumps was caused by the acid waste, as pointed out in the paper.

J. T. Campbell:* Mr. Laboon and Mr. Wickerham discussed to quite an extent the question of glass-covered sludge beds, stating that you get about three times the capacity from the glass-covered bed that you do from the open bed, which is true if certain precautions are taken. One factor must not be overlooked in northern climates. If the edges of the sludge bed are not protected they will freeze inside from three to five feet, and that will cut down their capacity so that while they may be designed for a capacity of 1/3 square foot per person you will not get anything like that if you do not protect against freezing in northern climates.

Philip S. Wickerham: That point is well brought out. It has been met in the Sharon and Butler designs by bringing the outside wall up to within about 29 inches of the eaves, or enough to permit side ventilation, and constructing an embankment around the outside, some two or three feet thick.

*Member, J. N. Chester Engineers, Pittsburgh.

P. W. Price:* I would like to ask the speaker if this plant at Fostoria, or any other plant of which he has had recent knowledge, is finding any market for sludge. Is the sludge becoming available for any use, or has it any market value at Fostoria or elsewhere? In this connection, it would seem to me that, if a process could be developed by which sludge could be treated in some inexpensive way (possibly by the addition of certain chemical ingredients) so that it could be changed from a worthless waste product, the final disposition of which is often troublesome, into a valuable by-product, a very important step forward would be achieved in the economics of sewage treatment. The sale of this material as fertilizer might help to pay for the efficient operation of the plant, the necessity for which was so well brought out by Mr. Laboon and others this evening. I have read that this has already been achieved to a considerable extent in Europe, and I wonder if it can not ultimately be carried out on a paying basis in this country.

J. F. Laboon: I think the cost of marketing sludge is so high as to be discouraging. I have seen the Houston, Tex., activated sludge and one or two other cases where attempts have been made to recover the sludge, at Baltimore particularly, in most of which cases the attempts have since been abandoned. At Houston they pulverized the burnt sludge marbles, packed the material in 100-pound sacks and sold it as fertilizer; but, so far, it has not proved economical. I do not know of any plant except Milwaukee, that has made any successful attempt to market the by-product. At Plainfield, N. J., they sold the wet sludge to the farmers for 25 cents a load, as was done at Baltimore, but pretty soon the farmers got sick of it. The increased quantities of grease that now prevail have a deleterious effect on the soil and the farmers will not take it at any price. As a matter of fact I think I can make the broad statement that there is no plant in the United States that is marketing its sludge profitably.

G. T. Pettay:† A question during this meeting, with regard to the state departments in Pennsylvania and Ohio, brought this to

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†Aires, Stone & Pettay, Pittsburgh.

my mind. In Pennsylvania we have in the Pittsburgh district one engineer and an assistant to look after seven counties. It is my understanding that, in addition to a study in the design of systems and works for the disposal of sewage, the district engineers in Pennsylvania are required to review the design of waterworks and are in responsible charge of the operation of such plants, the control of typhoid fever and nuisances, and other duties too numerous to mention. This makes it very hard to get plans promptly through the state department, either for approval, revision, or rejection. Personally, I know that the state engineers in this district are hard working and efficient. They are just overloaded with work. Typhoid has been epidemic lately, and the other work of the district engineers has been hampered. It seems to me that an increased personnel, where needed throughout the state, would help materially and unquestionably would increase the efficiency of the Pennsylvania department.

J. F. LABOON: I want to correct the speaker's statement regarding Ohio. They do not sub-district their work by counties. In fact, Pennsylvania is sub-districted, while Ohio is not. Ohio handles all its work from a central office, they have no district engineers as in Pennsylvania; so Pennsylvania would seem to be better organized in that respect than Ohio.

G. T. PETTAY: I have been given to understand by the physician in charge of the health department work of one of the Ohio counties that he has an engineer on his staff who looks after the general health as regards possibilities of typhoid infection, etc. It seems to me that a similar arrangement would relieve the state engineers who supervise the design, construction, and operation of waterworks and sewage disposal plants of a lot of detail work.

NATHAN B. JACOBS: It was not intended to get up a discussion as to the merits of two different state boards of health. They are both very hard-working boards and excellently manned. I do not think the criticism should apply either to the organization or the personnel. The real distinction between Ohio and Pennsylvania is in their laws. Our laws do not have teeth. The Department of Health does not have power to go into a borough and compel the borough to put in sewage disposal. The teeth in the enforcement of such laws is practi-

cally in the common law in Pennsylvania and you have to go through the office of the Attorney General; while in Ohio they do have the power to make an order, even one which would permit a municipality to exceed the constitutional limit of indebtedness, and they can get much better co-operation because they do have the power to carry out their orders.

In regard to the organization in Ohio, no doubt Mr. Pettay refers to the county sanitary engineer. His plans must go to Columbus to be approved, just like any other engineer's plans. The work is concentrated in Columbus. Here we have local offices in Williamsport, Pittsburgh, Philadelphia and a few other points.

J. F. Laboon: I did not intend any criticism of the department of health. I was unfortunate in making a statement of comparative activities. I mean that Ohio is more active because its laws make it possible for the health authorities to apply direct action.

G. T. Pettay: I do not want to be understood as criticizing the present Department of Health of Pennsylvania. My thought was, that this Society might help the Department in getting necessary legislation passed to further its power and efficiency.

Nathan B. Jacobs: Along that line, the Conservation Council in Pennsylvania has drafted a new act which can be obtained by writing to the council. From what I have seen in studying it and comparing it with work in other states, I think it is well worthy of sanitary and civil engineers getting behind it and getting more effective legislation for Pennsylvania.

J. F. Laboon: (*Author's closure.**) Since presenting this paper on the improvements to the sewage disposal plant of Fostoria, Ohio, bids were taken and contracts let on March 16, 1927. In addition to the letting of contracts on the predetermined improvements, contracts have also been let for several of the alternate items, such as the covering of sludge bed No. 4, by glass; the installation of Dorr clarifiers in the preliminary settling tanks; the installation of a 50-foot Dorr clarifier in the humus tank; the resurfacing and reconstruction of sludge bed No. 3; and the installation of two monorails for the

*Received for publication March 25, 1927.

removal of dried sludge, which improvements will double the area of the sludge beds and permit the use of sludge bed No. 3 or the open sludge bed during the summer months, if necessary; the installation of the Metropolitan system of trickling filtered bottom; and the adoption of universal pipe for the trickling filter distribution system.

The clarifiers adopted are of the revolving type as manufactured by the Dorr Company; but one humus tank is to be constructed and equipped with the revolving-type clarifiers in place of the two plain settling tanks originally designed and described in the paper. The detention period of the single tank has been reduced to one hour, based on the average flow, in contrast to the 1½-hour detention period of the combined plain settling tanks. It is believed that one hour detention in a single tank equipped with a clarifier is more than equal to the results which can be produced with 1½ hours detention in plain settling tanks. The contract prices follow:

Contract 12.	Excavation and grading complete plant	$116,596
	Rebuilding and equipping sludge bed No. 3	2,400
	Asphaltic joints in trickling filter	100
Contract 13.	Cast-iron pipe and findings	5,938
Contract 14B.	Universal pipe	3,569
Contract 15.	Gate-valves	739
Contract 16.	Valve boxes	91
Contract 17.	Sluice-gates	1,325
Contract 18.	Tide gates (Not required)	
Contract 19.	Hydraulic plug valves (Not required)	
Contract 20.	Check-valves	151
Contract 21.	Stone for trickling filter	17,938
Contract 22.	Nozzles for trickling filter	559
Contract 23.	Clarifier apparatus	15,590
Contract 24.	Pumps	7,400
Contract 25.	Chemical feed machine	363
Contract 26.	Venturi meter	1,342
Contract 27.	High-water alarm	200
	Total	$174,301

Estimated cost, less 10 per cent. for engineering and contingencies $180,000

STORY OF THE EFFORTS WHICH LED TO THE PURIFICATION OF THE WATER-SUPPLY OF PITTSBURGH, AND TO THE ELIMINATION OF TYPHOID FEVER FROM THAT CAUSE*

By James Otis Handy†

Vital statistics show that up to the year 1908, the first year of sand filtration of the Pittsburgh water-supply, typhoid fever, a terrible scourge, was unchecked, taking for its victims chiefly young people between the ages of 18 and 35. In 1906 and 1907 there were 10,000 cases, and 1000 persons died.

While there may have been sporadic efforts made, prior to 1893, to focus public attention upon the water-supplies of Pittsburgh and Allegheny as the sources of unnecessary sickness, causing financial suffering and death, the real work to that end began in that year. The sequence of events, based on public records, and on the recollections of those who took part in the investigation, agitation, etc., was as follows:

Engineers and chemists had been following with interest the investigations made just prior to that time by the Massachusetts State Board of Health at Lawrence, Mass., on the Merrimac River. The work there had for its object the study of sand filtration of the water-supply as a means of preventing transmission of typhoid fever. It was planned by, and was under the direction of Mr. Hiram F. Mills, hydraulic engineer, and associated with him were such men as Professor Thomas M. Drown and Professor William T. Sedgwick, of the Massachusetts Institute of Technology. It is notable that men trained at Massachusetts Institute of Technology have been responsible for much pioneer work in sanitation, and several graduates of this institution, as indicated in this paper, have been connected with the technical work of the Pittsburgh filtration plant.

In 1893 Lawrence installed a sand filtration plant, and the result was the anticipated one. Typhoid fever from drinking water ceased to be prevalent. Mr. Allen Hazen, M.I.T., '88, and Mr. George W.

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†Director of Chemical and Metallurgical Investigations, Pittsburgh Testing Laboratory, Pittsburgh.

Fuller, M.I.T., '90, were employed on the work at Lawrence. Mr. Morris Knowles, M.I.T., '91, was assistant engineer, under Mr. F. P. Stearns, chief engineer.

Mr. Hazen's studies in Europe showed him that all water-borne diseases, from cholera through typhoid fever to various undifferentiated forms of intestinal disorders, could be eliminated by sand filtration of the water-supply under proper conditions. In 1895 he published a book entitled "Filtration of Public Water-Supplies."* This book, his published articles, and his public addresses, received very wide attention, and increased the desire on the part of those having inferior water-supplies to subject them to purification by sand filtration.

It had been the custom for many years prior to 1893 to classify waters as to their degree of purity by chemical analysis, which determined the amount of nitrogenous organic matter, the theory being that this organic matter had been chiefly derived from animal waste discharged into the stream serving as a water-supply. Chlorin was considered in some quarters as an indication of contamination. The unreliability of chemical analysis as a guide was already recognized by most of those concerned, and bacteriological control was beginning to supersede chemical methods.

In the first studies of the Pittsburgh water-supply, chemical methods of investigation were used, but their futility was demonstrated and subsequently analyses were disregarded by everyone except those who believed that the supply was not contaminated, and who found some doubtful comfort in indeterminate figures.

The self-purification of streams was a theory which found favor for many years, and which had in it a certain element of truth, but under stream-flow conditions such as were normal above Pittsburgh, the time for purification of the sewage-contaminated water traveling from one community to the next was entirely too short. The self-purification theory was also relied upon by those who could not be convinced that the water-supply of Pittsburgh and Allegheny was contaminated.

Intensive study of the water-supply of Pittsburgh, and of the problem it involved, began in 1893 after the presentation by a chemist, Samuel G. Stafford, before the Chamber of Commerce, of some unfa-

*John Wiley & Sons, New York.

vorable results of an examination of Pittsburgh city water. A committee, consisting of Mr. Reuben Miller, Colonel T. P. Roberts, and Mr. Joseph Abel, was appointed and instructed to ask for the appointment of joint committees of the Engineers' Society of Western Pennsylvania and of the Allegheny County Medical Society to study the water-supply problem of Pittsburgh.

The co-operating committee of the Chemical Section of the Engineers' Society of Western Pennsylvania, consisting of Messrs. F. C. Phillips, R. M. Clarke, Philo Kemery, Theodore Hopke, and James O. Handy, was appointed on March 28, 1893, at a meeting of the Chemical Section of the Society, after the reading of a paper by Mr. James H. Harlow on "The Water-Supply of Pittsburg and Allegheny City."*

Mr. Harlow's paper, which showed clearly the increasing and already serious contamination of the Allegheny River by sewage, and the rapid character of the river flow, which brought the sewage of other towns on the watershed quickly to the Pittsburgh waterworks intake, was discussed by Dr. F. LeMoyne, Mayor William M. Kennedy of Allegheny, Mr. Alexander Dempster, Colonel T. P. Roberts, and others.

The following engineers were appointed to represent the Engineers' Society of Western Pennsylvania on the Joint Commission, which also included representatives of the Chamber of Commerce, the Allegheny County Medical Society, and the Iron City Microscopical Society: Mr. George S. Davison, Mr. Samuel Diescher, Mr. G. Kaufmann, Mr. Charles Davis, and Mr. James H. Harlow, Secretary of the Engineers' Society of Western Pennsylvania.

The chairman of the Joint Commission was Mr. James B. Scott. Mr. W. Lucien Scaife, an engineer, was later added to the Chamber of Commerce committee of the Joint Commission. Dr. F. LeMoyne, Dr. A. J. Davis, Dr. J. M. Duff, and Dr. E. G. Matson represented the Allegheny County Medical Society, while Mr. George H. Clapp, Mr. George P. Taylor, and Professor J. H. Logan represented the Iron City Microscopical Society. Mr. George W. Guthrie and Mr. C. C. Briggs were later added by the Commission. *Ex officio* members were Mr. E. M. Bigelow, Director of Public Works; Dr. J. Guy McCandless, and Mr. F. F. Meyer.

*PROCEEDINGS, v. 9, p. 109-124.

The work of the Joint Commission was carried on from the spring of 1893 to October of that year. Its report, favoring sand filtration of the water-supply at the earliest possible moment, was published and appeared in February 1894. The report contained committee reports and individual reports upon the character of the water-supply, and upon the means of obtaining a better one, either by an aqueduct, or by filtration. Filtration was decided upon and recommended as the most practicable means.

The report was in no uncertain tone. It said:

> "It is the opinion of your committee that the water now being delivered by the cities of Pittsburgh and Allegheny to their populations is not only not up to a proper standard of potable water, but is actually pernicious. . . .
>
> The vital statistics during a period of twenty years show a larger percentage of deaths from that cause [typhoid fever] in Pittsburgh and Allegheny than any other city in the United States. . . .
>
> It is a matter of urgent importance and absolute necessity to remove from the water the ingredients which are most pernicious. That can probably best be accomplished by a system of general filtration."

In 1895, there remaining no doubt of the contamination of the Pittsburgh water-supply, and no doubt that sand filtration of similar supplies had eliminated water-borne diseases from the communities served with those supplies, there seemed to be only two things left to do:

1. To show that with the local sand and gravel available at Pittsburgh the city water-supply could be purified so that it would be freed from disease germs.

2. To convince the whole community of the necessity for filtration of the public water-supplies.

While the second matter would naturally wait upon the first, yet the favorable outcome of our sand filtration experiments was to be expected, and therefore public information concerning the general subject was furnished while the experiments on sand filtration were being carried out.

The idea of public demonstration of the feasibility of sand filtration in Pittsburgh, using local sand and gravel, was that of the writer, Mr. J. O. Handy, M.I.T., '88, who, through his connection with the Chemical Section of the Engineers' Society of Western Pennsylvania and with the Pittsburgh Testing Laboratory had been in close touch with water conditions in Pittsburgh and elsewhere.

Early in 1895 the matter was brought before the Citizens' League—an organization of public-spirited young men, chiefly connected with the First Unitarian Church. The plan was approved and adopted.

Public demonstration having been decided upon, public subscriptions were asked for, and the sum of $700 was raised without difficulty, the contributions coming from engineers, physicians, business men, and others. Among the contributors were Andrew Carnegie, George W. Guthrie, William M. Kennedy, and Judge Thomas Ewing. Subscriptions were numerous and gratifyingly prompt. Persons in moderate circumstances gave gladly.

Engineers contributed a design for the filter, and materials for its construction were very largely donated. The filter was erected on the Unitarian Church lot on Craig Street near Fifth Avenue, and was put into operation on September 22, 1895, continuing in operation, under bacteriological control, until September 24, 1896.

This experimental filtration tank was 6¾ feet in diameter, and 6½ feet high, with a capacity of 1500 gallons. Stud rods of 7/16 round steel, 15½ inches between centers, were framed into a channel bar at the top, and inserted in a concrete platform below. This framework was covered with expanded metal lath and inclosed in two-inch walls constructed of a mixture of one part "Alpha" Portland cement to two parts sand. Fig. 1 and 2 illustrate the construction of the tank.

The results proved beyond any question that Allegheny River water could be purified satisfactorily by means of a filter containing Allegheny River sand.

This demonstration, accounts of which appeared in the *Engineering News*, December 12, 1895,* the *Pittsburg Medical Review*, December 1895,† and in the *Pittsburg Dispatch*, December 29, 1895, removed all doubts from the public mind that the river water at Pittsburgh was contaminated, and that it could be purified by filtration through the local river gravel and sand.

The newspaper interview of December 29, 1895, in which Mr. J. M. Hudson, editor of the *Pittsburg Dispatch*, quoted the writer on the various aspects of water filtration in the world at large, and Pittsburgh in particular, had somewhat wider circulation than the engineering and medical reports which had already been published, and

*V. 34, p. 390-391.
†V. 9, p. 370-371.

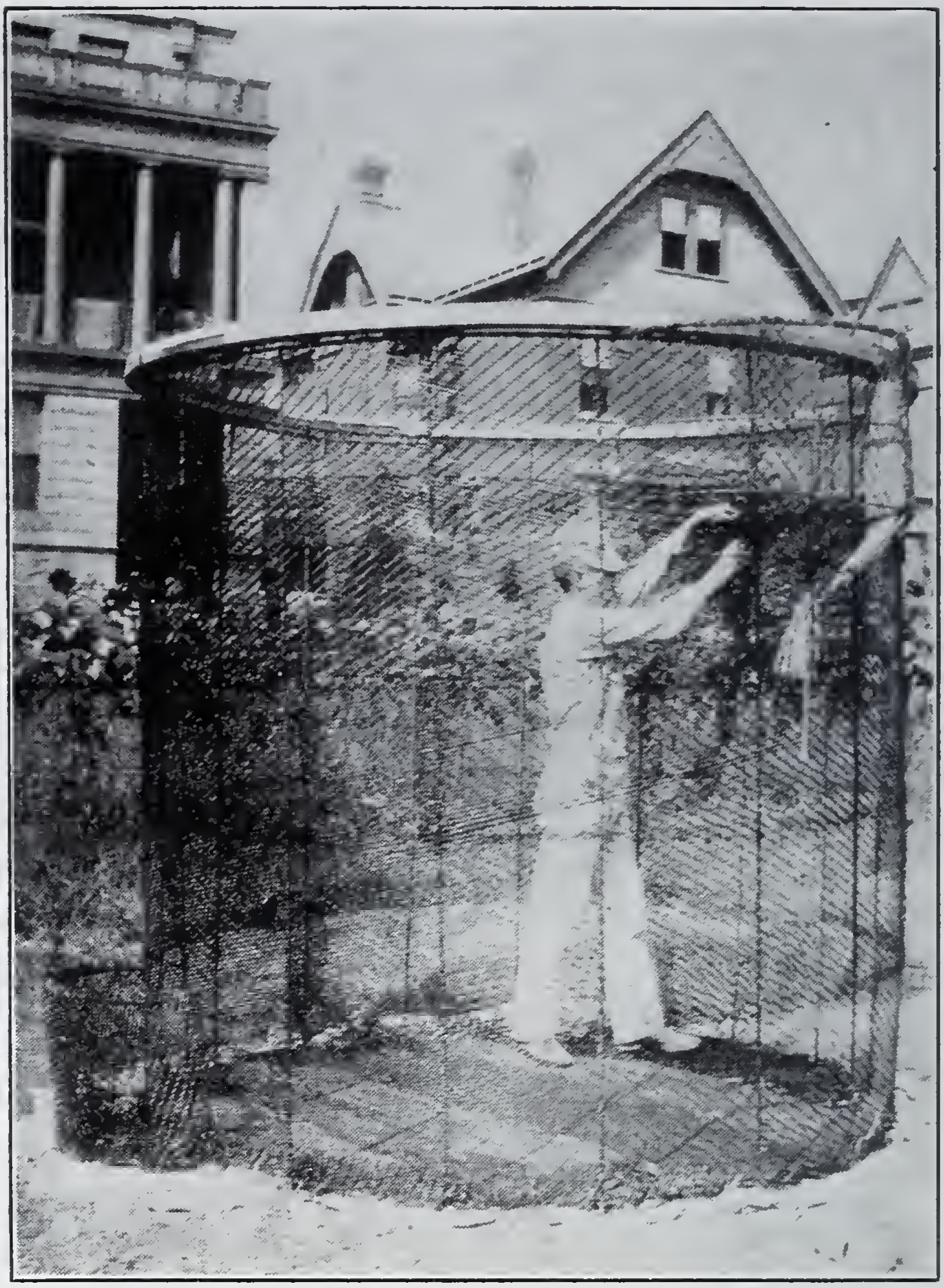


Fig. 1. Framing for Experimental Filtration Tank.

helped more completely to prepare the public mind for sand filtration. Fig. 3 is reproduced from the beginning of this newspaper article.

It was believed necessary, however, to prepare the public mind still further by a more detailed official study of the water purification problem of Pittsburgh and Allegheny. For this purpose the Mayor of Pittsburgh, Hon. Henry P. Ford, appointed the Pittsburgh Filtration Commission. This appointment took place on the basis of an ordinance approved by the councils of Pittsburgh on June 8, 1896, which was as follows:

"Whereas, Recent advancement in sanitation in the direction of agitation for the filtration of public water supplies to remove the pollution, which comes from increase of population along the banks of the supplying streams; and

Whereas, Investigations and experiments in this direction, while limited in practical operation to but one city in the country, have nevertheless gone far enough to command the careful consideration of a progressive city such as Pittsburgh; therefore,

Resolved, That a Commission be created, of which the Mayor of the city and the Presidents of the Councils, and eight representative citizens and taxpayers to be appointed by the Mayor shall be members, at least two of whom shall be physicians of recognized standing.

Resolved further, That it shall be the duty of this Commission to thoroughly investigate as to the character of our present water supply in its relation to the public health, the effect of sand filtration and the advisability of establishing and maintaining the same; and also to investigate the feasibility and advisability of seeking other sources of supply.

And the Commission shall report its findings and recommendations together with such evidence as may be useful for the guidance of these Councils in acting prudently and for the best public interest in this matter."

Fig. 2. Completed Tank.

PITTSBURG DISPATCH

Dec. 29, 1895.

DRINKING IN DEATH.

Fatal Diseases in the Water Furnished Pittsburg and Allegheny.

HUMAN LIVES SACRIFICED

By the Failure of the Municipalities to Purify the Supply.

JAMES OTIS HANDY INTERVIEWED

He Makes a Strong Plea for the Adoption of Sand Filtration.

ECONOMICAL AND EFFECTIVE SYSTEM

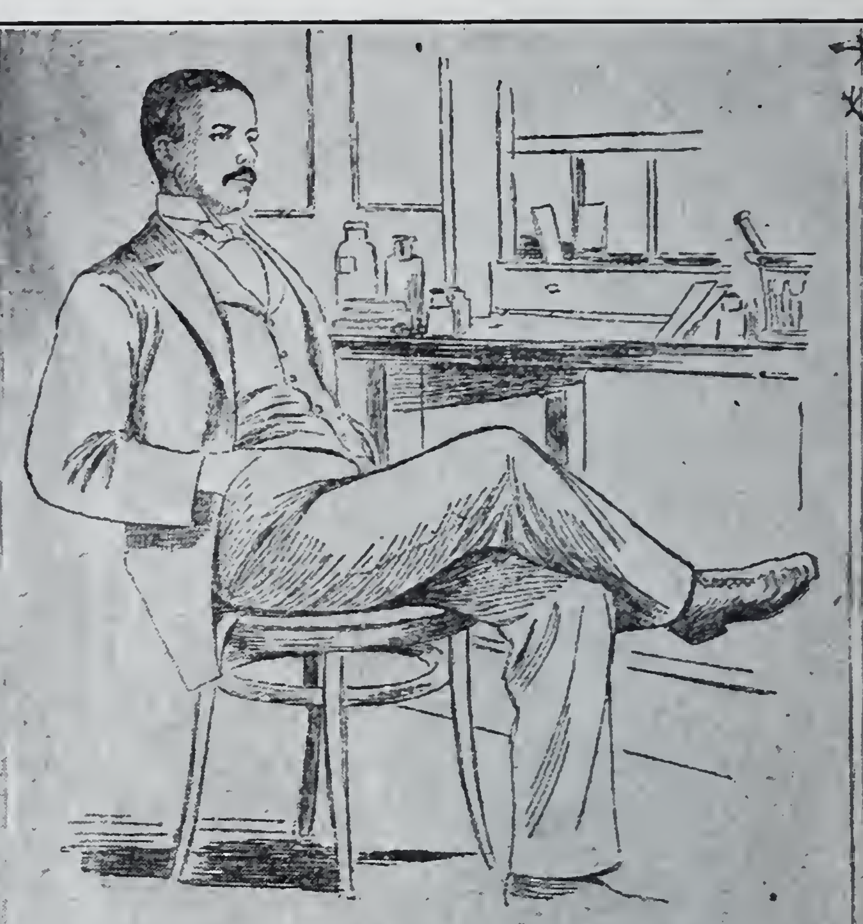
Since the rapid growth of Pittsburg up-river suburbs has forced upon the people the necessity of improving the water supply, there has been a number of thoughtful, educated, experienced and public-spirited men who have taken a long step in advance. They recognized the gravity of the situation even while the city officers had not thought of it, and laid it before the people even while the municipal guardians were trying to distract public attention by chemical tests that did not test.

For several years this coterie, with the aid of the public-spirited press, led by The Dispatch, had labored to waken the community to the dangers that lay in the reservoirs of the two cities and were carried through the water pipes into the very homes of the people. But it was not until the present year that the people generally realized the importance of the warning.

The devastating epidemic of typhoid fever that began at Freeport, Springdale and Tarentum, and followed the course of the river with increasing virulence until it reached Pittsburg and Allegheny, numbering its victims by the scores and causing the people to hesitate even to slake their thirst with a glass of city water, has had its effect. Now there is a widespread public demand on the city government for a pure, healthy water supply. It was a costly lesson, and it required a long time to learn, but it has apparently come at last.

Demonstration of Sand Filtration.

Again the men who were the first to sound the danger signal are now the first to prescribe a remedy for the great evil. They have studied them all, and with the advantage of scientific discretion have selected the one best suited to the case, both from sanitary and financial points of view. They have made a public demonstration of their remedy, sand filtration, and it is open to the investigation of all who wish to see. It has convinced thousands of its adaptability and has attracted attention all over the country as a solution of the water problem of inland cities.



"ANYTHING IS BETTER THAN THE PRESENT CONDITION OF THE WATER SUPPLY IN PITTSBURG AND ALLEGHENY."

Pittsburger by adoption, having come here from Baltimore seven years ago. He was chemist there of the B. & O. Railroad Company, having previously occupied the same position with the Union Pacific Railroad at Omaha.

A Native of Massachusetts.

Mr. Handy is a native of Barnstable, Mass. He is a graduate of the Massachusetts Institute of Technology, of Boston. There he was a student under Dr. Thomas M. Brown, who is perhaps the best authority in this country on the water question, and whose reputation is international. Dr. Brown, by the way, is to be in Pittsburg next week to discuss this question, by request of the Citizens' League, an organization of which Mr. Handy is a prominent member.

Personally Mr. Handy is a pleasant gentleman, modest and reserved in manner almost to diffidence, yet, having convictions, is courageous in expressing them. He is the kind of man who impresses one with his sincerity and honesty of purpose without taking the trouble to try.

I found Mr. Handy in his laboratory on Water street, in the midst of an analysis of a sample of nitro-glycerine. As he worked he talked. Now and then he would take up and discuss one of several little glass dishes in which were cultures of germs he has taken from day to day from the city water supply. These cultures, when first taken, are much too small to inspect through a powerful microscope, yet by the culture process they grow and increase so that in a few days there are countless millions of them, and they completely cover the bottom of the culture dishes.

Interested in Pure Water.

"I became interested in the question of pure water supply," said Mr. Handy, "in 1891, when, at a meeting of the Engineers' Society of Western Pennsylvania, a paper was read by James Harlow on the water supply of

filtration, by the European method of sand filtration, and by so-called natural filtration, which is the system they intend to use in Allegheny at Nine-Mile Island.

Purification by Sand Filtration.

"The conclusion of the majority of the engineers and physicians was that water should be taken from the Allegheny river and purified by sand filtration. They recommended going a short distance further up the stream to avoid some of the contamination which the river receives just above the present water works. The water was to be taken and filtered at a rate not exceeding 2,000,000 gallons per day.

"As Pittsburg is said to use about 41,000,000 gallons per day, the filter area required would be about 18 acres, with a necessary reserve of about four acres more. The engineers concluded from their investigation that the present rate of consumption is excessive and probably twice what it would be with proper economy. If meters were introduced the amount of water to be pumped would be much less and the filtering area which would be required for the

See * above for the continuation

Fig. 3. Heading of Newspaper Article Which Gave Valuable Publicity to Filtration Project.

The members of the Commission, as appointed, and their officers, as later chosen, were Robert Pitcairn, chairman; William McConway, vice-chairman; George L. Holliday, secretary; W. J. Holland, S. D. Warmcastle, Dr. J. R. Vincent, J. Guy McCandless, James H. Bailey, William Flinn, E. M. Bigelow, and Mayor Henry P. Ford.

Dr. Holland took an active and generous part in organizing and assisting in the work of the Commission. It was a labor of love for him and for most of his associates.

The Commission appointed Allen Hazen, consulting engineer; Morris Knowles, resident engineer; Dr. Walther Riddle, chemist, and W. R. Copeland, bacteriologist.

An experimental filtration plant, in which several methods of filtration were compared, was erected near Brilliant pumping station, and operated from May 1897 to September 1898.

Reports were made on the "Sources of Typhoid Fever in Pittsburgh" by Professor W. T. Sedgwick, and on a "Gravity Water Supply from Indian Creek" by E. Kuichling, and were included in the report of the Commission, together with the reports of the consulting and resident engineers. A. B. Shepherd made a report on the feasibility of a driven well water-supply for Pittsburgh.

The expenses of this Commission did not include the personal expenses of the members of the Commission while visiting and inspecting filtration plants, and amounted to only about $41,000.

The report was made in 1899 and published in 1900. It recommended sand filtration.

Shortly after the appearance of this report, which added much valuable detail, but confirmed whole heartedly the recommendations of the Joint Commission made in 1894, six years earlier, the public were asked to vote on a bond issue of $2,500,000 for a sand filtration plant for the water-supply of Pittsburgh. This was approved by the people prior to June 1, 1900, and plans were prepared. In view of the desirability of providing filtered water for the entire city, including both Allegheny and the South Side, the original plans were modified, and another bond issue was authorized, bringing the total money available for the filtration plant up to $7,500,000. (A part of this increase could have been avoided if a land option secured by the Filtration Commission had not been allowed to lapse.) This author-

ization of bonds took place on July 12, 1904, and provided for covered filter beds.

Just before this (on March 5, 1904), the *Engineering Record* had said, editorially, "Pittsburg surely has sufficient resources to follow the . . . plan, and cease juggling with the lives of its citizens."* On July 16, 1904, the same authoritative publication had said, "The city [Pittsburgh] is so manifestly in need of better water that it is difficult to understand the mental make-up of those who oppose the construction of purification works."†

In February 1905 the authorities approved the revised plans, which were also approved by the eminent engineers, Rudolph Hering, J. W. Hill, chief engineer of the Philadelphia filtration plant, and Colonel A. N. Miller, chief engineer of the Washington, D. C., filtration plant.

The Bureau of Filtration was created, and Morris Knowles was made Chief Engineer of Design and Construction. He was assisted by F. E. Field and Thomas H. Wiggin, both of whom passed on later to other important positions in the municipal water-supply field.

On March 12, 1905, the contract for the construction of the filter beds was awarded to the T. A. Gillespie Company.

In the fall of 1907 the filter plant was rapidly approaching completion, and descriptions of it appeared in the *Engineering Record*,‡ supplementing the articles which began in that publication in 1906. In 1910 the plant was described by F. E. Field before the Engineers' Society of Western Pennsylvania.§

The filtration plant was finally put into operation in 1908, 15 years after the decision and announcement by a group of engineers, chemists, and physicians that sand filtration was necessary and apparently practicable for Pittsburgh. In 1909 the South Side, and in 1914 the North Side (formerly Allegheny), were also supplied.

Typhoid fever had taken heavier toll each year until the plant started. Had the plant been built, even in 1900, much money and over three thousand lives would have been saved.

From the start the well designed and well built filter plant has been operated with skill and fidelity, and for this important accom-

*V. 49, p. 266-267.
†V. 50, p. 67.
‡V. 54, p. 622, 664, 694, 713; v. 56, p. 384.
§PROCEEDINGS, v. 26, p. 233-269.

plishment the people have to thank Chester F. Drake, M.I.T., '98, who has had charge of the plant from the start, and also all those who have co-operated with him (W. U. C. Baton, M.I.T., '05, and others). Sickness and death from typhoid fever and other water-borne diseases have been practically eliminated.

The last investigative work bearing on typhoid fever conditions and the necessity for filtration was done by the "Typhoid Fever Commission" composed of Dr. Dixon, Dr. Edwards, Dr. Rosenau, Dr. Boise, Dr. Matson, and Mr. Morris Knowles. This work was done between 1910 and 1912, and a copy of the report in manuscript is in the Carnegie Library of Pittsburgh.

There has been much discussion as to the gain due to prevention of typhoid sickness and death in a community such as ours. In the 12 years before 1908, there were 4600 deaths from typhoid, and the cases of serious illness from that cause, but not resulting in death, undoubtedly amounted to ten times that number. The loss to the community in money alone, if each life were valued at $5000 and each case at $300, amounted to $30,000,000 more than the filter plant cost. It is not extravagant to say that sand filtration has saved us $60,000,000 already. It has saved also the immeasurable service of individuals whose great and special contribution to the community might have otherwise been lost.

In 1893, and up to the time when filtration was adopted, Pittsburgh and Allegheny had more typhoid fever cases than any other cities in the world. With filtered water, Pittsburgh stands high in the list of enlightened cities of the world. The typhoid fever deaths annually per 100,000 population averaged 127 during the 12 years before 1908. Since 1914 the rate has averaged only six. In 1925 and 1926 it was under three. Some of the results are indicated graphically in Fig. 4.

In order to re-create in a measure the atmosphere in which the work for a better water-supply for Pittsburgh was carried on, the following notes showing the personalities of those most concerned are added.

E. M. Bigelow, Director of Public Works of Pittsburgh in 1893 and afterward, was an active and efficient civil engineer and administrator, who rendered great service to Pittsburgh as a builder of parks and boulevards. He did not share our belief that the water

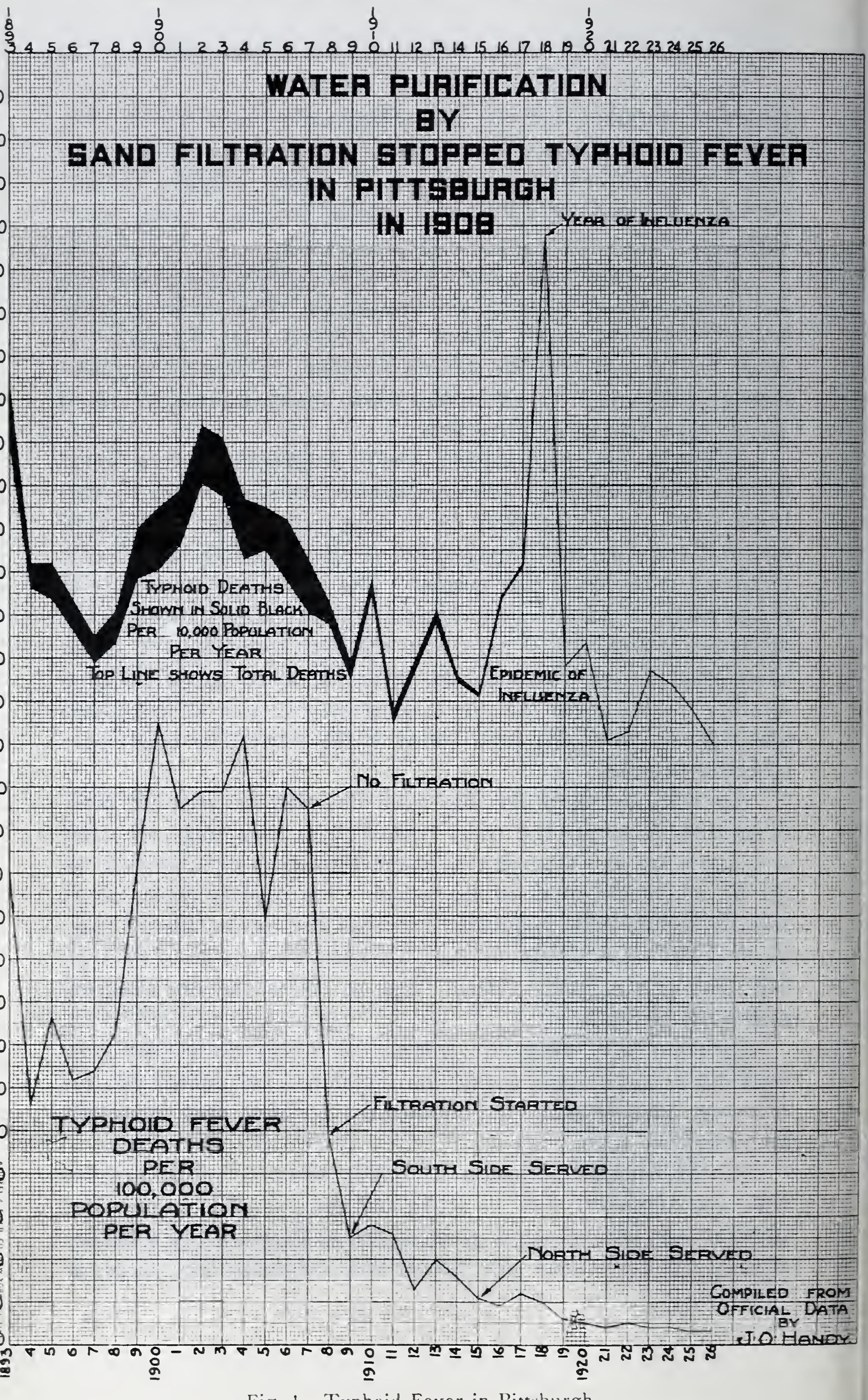


Fig. 4. Typhoid Fever in Pittsburgh.

was bringing typhoid fever to Pittsburgh. He seemed to feel a personal responsibility for the water-supply. He never admitted that the water was disease bearing. Even after the careful work of the Filtration Commission, of which he was a member, had shown to all his associates the need and the remedy, Mr. Bigelow would sign the report only with the understanding that he did so merely to make clarified water for bathing, etc., available to the people of Pittsburgh. He was absolutely consistent in his disbelief in the contamination of the water-supply; therefore, in his opinion, there was no need to purify it. He accused us of infidelity to the business interests of our city in questioning the purity of our water-supply. The writer's reply to this in the *Pittsburg Dispatch* interview was, "It is not the agitation which does the harm, it is the fact that the water is impure."

A man of great force and influence, Mr. Bigelow opposed the movement for purer water most strenuously, and we outspoken crusaders were regarded as his personal critics and enemies. Some of us, who were young and new to Pittsburgh, were warned by our employers to be less outspoken in view of the very unfriendly attitude of this important authority. We were, however, too full of zeal to bring on the day of release from unnecessary sickness and death to take such warnings seriously.

Our work went on. We were right. Mr. Bigelow was not. He has a monument in Schenley Park, but none at Aspinwall, our great filter plant. It is only fair to say that when the public voted for a plant, Mr. Bigelow saw to it that a plant was built according to the best advice obtainable.

A word in conclusion as to those who worked early and late for the idea until it was realized.

Dr. LeMoyne, kindly, wise, energetic physician; Dr. Matson, bacteriologist, keen student of our problem, and convincing writer and speaker; Professor Phillips, modest, zealous, talented chemist; Mr. Davison and his engineer associates, contributing gladly their practical advice on our great sanitary engineering problem; Dr. Holland and Mr. Clapp, throwing their influence as university men on the side of filtration; Dr. Koenig and Mr. Hudson, editors, publishing in their papers the case against the water-supply and the way out; these names are typical of the workers early in the field.

Besides those of us whose lot it was to give our time and thought were those men who were engaged to tell us just what to do, and how to do it. Their advice was of great importance. We shall always honor the names of Allen Hazen and his associates for their clear thinking, writing, and advice; of Morris Knowles for planning and building so well the great filtration plant; and of Chester Drake for operating it efficiently under changing and always difficult conditions, so that it has protected the community now for nearly twenty years.

It has been my wish to tell, as historian and friend, the story of the crusaders who have passed on, and of the few who are still with us. We all felt that we held in trust the knowledge of the means of relieving our fellow citizens from needless suffering and death. In our several ways we labored, finally with success, to discharge this trust.

TREND IN LARGE TURBO-GENERATOR DEVELOPMENT*

By L. T. Peck†

The dictionary defines the word "trend" as "General course or direction as in movement toward a particular point."

If we consider turbo-generator sets of great capacity as the objective of the industry, then some of the orders placed during 1926 certainly indicate that the trend is in this direction, and perhaps a more positive word than trend should be used to describe a movement which took on such extraordinary impetus during the last six months of the year just closed. As a matter of fact, the trend in turbo-generator development since its beginning in the 'nineties has been constantly toward larger units, and while the engineer of to-day has reached heights never dreamed of by the engineer of yesterday, it should be remembered that not only does he profit by the experience of his predecessors and have better materials with which to work, but he has the enormous advantage of a created market which takes the best he can produce and urges him to greater endeavor; whereas the pioneers were not only handicapped by meager data, but were faced with the difficult problem of inducing the operators to buy machines they did not want.

For many years the power industry lagged behind the development engineer and it is only within a comparatively short time that it caught step. Now it seems in a fair way to get out of step again with a demand for super-units which may be beyond our manufacturing capacity with existing equipment. This demand for increased unit output was made possible by the parallel development, along with the turbo-generator, of switching equipment capable of handling the loads involved, and high-voltage transformers and line equipment for power transmission, and became desirable when the successful operation of high-tension lines led to system interconnection, followed by the merger of systems under common ownership and management and the establishment of base-load plants.

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†American Brown Boveri Electric Corporation, Philadelphia.

The fact that the generation of electric power has taken on the proportions of mass production at strategically located plants of large capacity, with the elimination of many small plants, does not in itself mean that units of extraordinary capacity are required, or in many cases even desirable, and it would be unwise to assume that the power-plant of the future will be planned on this basis, as there are too many factors which have to do with the economics of power production to warrant any such assumption.

The primary concern of every operator is excellence of service, with cost of production as of next importance, and, while there is no more service risk in operating a 40,000-kilowatt, single-cylinder turbo-generator set than in operating one of 20,000 kilowatts, the effect of a forced shut-down on the service rendered may be serious in one case and negligible in the other. Obviously, a multi-cylinder or cross-compound unit increases the operating hazard, and a three-machine, triple-expansion combination, to paraphrase a familiar expression, "places still more eggs in one basket." It would seem, therefore, that unit capacity will be governed primarily by station or interconnected capacity, and secondarily, by the economics of installation and production. These latter include, roughly, space available in existing stations, the cost of land and buildings for new sites, load-factor, installation cost per kilowatt, and cost of operation.

Throughout the electrical industry there seems to be a general idea that there must be some sort of fixed law which governs the cost of electrical machinery whereby the cost per kilowatt automatically decreases as the rated output or the speed is increased, and to a certain extent this is true after the manufacturer has succeeded in absorbing or writing off the initial cost of developing the larger machine; but it should be borne in mind that—aside from the development expense—the special tools, the individual operations, and the material of special grade required, all cost more. Turbo-generators of exceptional capacity thus seldom cost less per kilowatt than moderate-sized machines and, from the manufacturers' standpoint, the installation of one 90,000-kilowatt unit instead of three of 30,000 kilowatts represents a reduction in a profit which at best is very moderate. However, the manufacturer must be alert to the requirements of his clients and, if possible, anticipate them, so when it was recognized that units of enormous size could be profitably used in

some instances, every effort was made by the designer to discover new methods of raising the so-called limit of existing designs and to apply new ideas to approved construction.

Obviously, mere size with indifferent operating characteristics has no place in this new development and, while this paper deals primarily with the generator end, the trend of development depends largely upon the steam-turbine, and any discussion of limits should include both.

With respect to the generator, one of the previously recognized limitations, that of ventilation, has been greatly raised, if not completely removed. The mechanical bracing of stator coils is believed to be adequate to prevent damage to the windings under short-circuiting, regardless of size, and, as the inherent characteristics are under the control of the designer with assurance of stability, the limit as to size for a given speed is largely dependent upon the success of the metallurgist in producing a material which will enable us to increase the peripheral speed of the rotor beyond that which is now considered the maximum safe speed.

At the present time there is under construction a turbo-generator of 88,250 kilovolt-amperes to operate at 1800 r.p.m., and it is of interest to note that the diameter of the rotor will be 58 inches, with a resultant peripheral speed of about 455 feet per second.

Taking into consideration the safety factor represented by testing at 25 per cent. overspeed, we are inclined to believe that, with existing materials, a diameter of 60 inches at 1800 r.p.m., corresponding to 470 feet per second, is the limit of good practice, and therefore the present capacity limit at this speed, so far as diameter is concerned. If this is correct, the length of rotor will determine the ultimate capacity of a machine of 1800 r.p.m. The generator of 88,250 kilovolt-amperes will have a length between bearings of approximately 21 feet, 6 inches, which is well within safe limits, but no prediction can be safely made as to maximum permissible length of rotor for a given diameter, as there are too many factors to be considered. Furthermore, such a prediction would record us as to ultimate capacity, and in the light of progress made in the past few years this might be both undesirable and misleading.

The generator referred to is that on the high-pressure end of a cross-compound set of 160,000 kilowatts at 85 per cent. power-factor

being built by the American Brown Boveri Electric Corporation for the Hell Gate station of the United Electric Light and Power Company of New York. The generator on the low-pressure end will have a capacity of 100,000 kilovolt-amperes and the speed will be 1200 r.p.m. In this case the rotor diameter is approximately 80 inches, with a peripheral speed of about 419 feet per second, and the distance between bearings will be the same as for the generator of 88,250 kilovolt-amperes. The rotor of the smaller machine will consist of three forged parts, the middle one being a hollow steel cylinder, while that of the larger will be made up of forged steel disks shrunk onto a cylindrical shaft, this type of construction being used owing to the difficulty of procuring a forged cylinder of the diameter required.

In the matter of ventilation, it has been found advisable to abandon the practice of placing the impellers inside the end bells (since this form of construction necessarily limits the size and shape of the impeller blades), and, instead, to employ a specially constructed fan designed to give good efficiency in handling the volume of air needed for cooling. This is located in a separate casing between the bearing and the direct-connected exciter.

A closed-circuit cooling system will be employed, the direction of air being downward through the generator. The volume to be handled by each fan will be approximately 2100 cubic feet per second for the high-speed generator and 2300 for the lower speed.

The brief description given above of the Hell Gate station generators will serve to show what is being done in a particular instance where exceptional capacity in a limited space with moderate steam conditions was desired; and, while indicative of the capacities easily feasible, it is not intended to convey the impression that the most economical unit of the future from the standpoint of investment and economy will be a combination of maximum-size generators at given speeds driven by high- and low-pressure or high-, intermediate-, and low-pressure turbines. As a matter of fact, when service, weight, cost, and space are of equal consideration, the best unit in the opinion of many is the single-cylinder so-called "limit" turbine having the highest speed for a given output or the highest output for a given speed. This turbine is limited as to number of stages by the length of shaft, and in exhaust area by the length of blading. With the

exhaust area fixed for a given design, the output is governed by the vacuum carried, falling off as the vacuum is increased, with consequent increase in volume of steam passing through the leaving area.

Where the operating economy is of first importance, with ample space available, the multi-cylinder, single-shaft unit with no restrictions as to length (with attendant limitation of stages and leaving area) can be constructed for outputs equal to those of the largest generators yet designed, and gives exceptionally good performance, not only in these sizes, but when used with relatively small generators.

No discussion of the possibilities of machine design should overlook the limitations that weight and dimensions impose upon the manufacture, shipping, and handling of apparatus of enormous size. Probably no shop is to-day equipped with tools of sufficient size to handle machines of maximum permissible output, and the installation of expensive equipment which may be seldom used is at best a dubious investment. Crane capacity and the ability to handle heavy masses rapidly are other requirements difficult to provide for, and the question of shipping becomes of serious importance where tunnels are encountered.

Some figures in connection with the Hell Gate turbine will give an idea of the weights to be dealt with, and an indication of the masses which will have to be handled when larger machines are built.

	75,000 kilowatts 1800 r.p.m.	85,000 kilowatts 1200 r.p.m.
	Weight in tons	
Complete stator	130	150
Complete rotor	60	100

In this case the heaviest piece for transportation will be 110 tons, and the heaviest piece for erection will be 150 tons.

STEAM-TURBINE DEVELOPMENT*

By Walter B. Spellmire

It is, of course, understood that my discussion, or analysis, of the trend in steam-turbine development is based entirely on the experience of the General Electric Company, with whose turbines I am most familiar.

This company has approximately 17,000,000 kilowatts of steam-turbines in operation and a graphical study, through charts which show what the trend has been for the past 23 years, seems the most logical basis for analyzing what may be possible in the future. I take the 23-year period starting in 1903 for this purpose, because the large turbine industry is generally considered to have started with the installation in that year of a 5000-kilowatt turbine of 50 per cent. overload capacity in the Fisk Street station of what is now the Commonwealth Edison Company of Chicago. This turbine was not only several times the capacity of any previous turbine, but it was installed in the first power-house designed and laid out exclusively for steam-turbines.

The economy of this unit was favorable, as compared with other types of prime movers then available, and its cost was so low and involved such an appreciable reduction in building costs on account of its relatively small physical dimensions, that the use of this type of unit spread rapidly through the infant central-station industry.

The installation of large steam-turbines 23 years ago was justified by the reduction their use made possible in the cost of generating power. This has been the driving force behind all turbine development. A demand was made by the engineers and executives of the power-generating industry on the manufacturers for constant improvement in power-generating apparatus.

The increase in capacity in General Electric machines installed in the years since 1903 is shown in Fig. 1. You will note that this has been projected to cover the year of installation of several record-breaking machines now on order.

The State Line Generating Company is to install a 208,000-kilowatt, cross-compound turbine generator in its new generating sta-

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†Manager, General Electric Co., Pittsburgh.

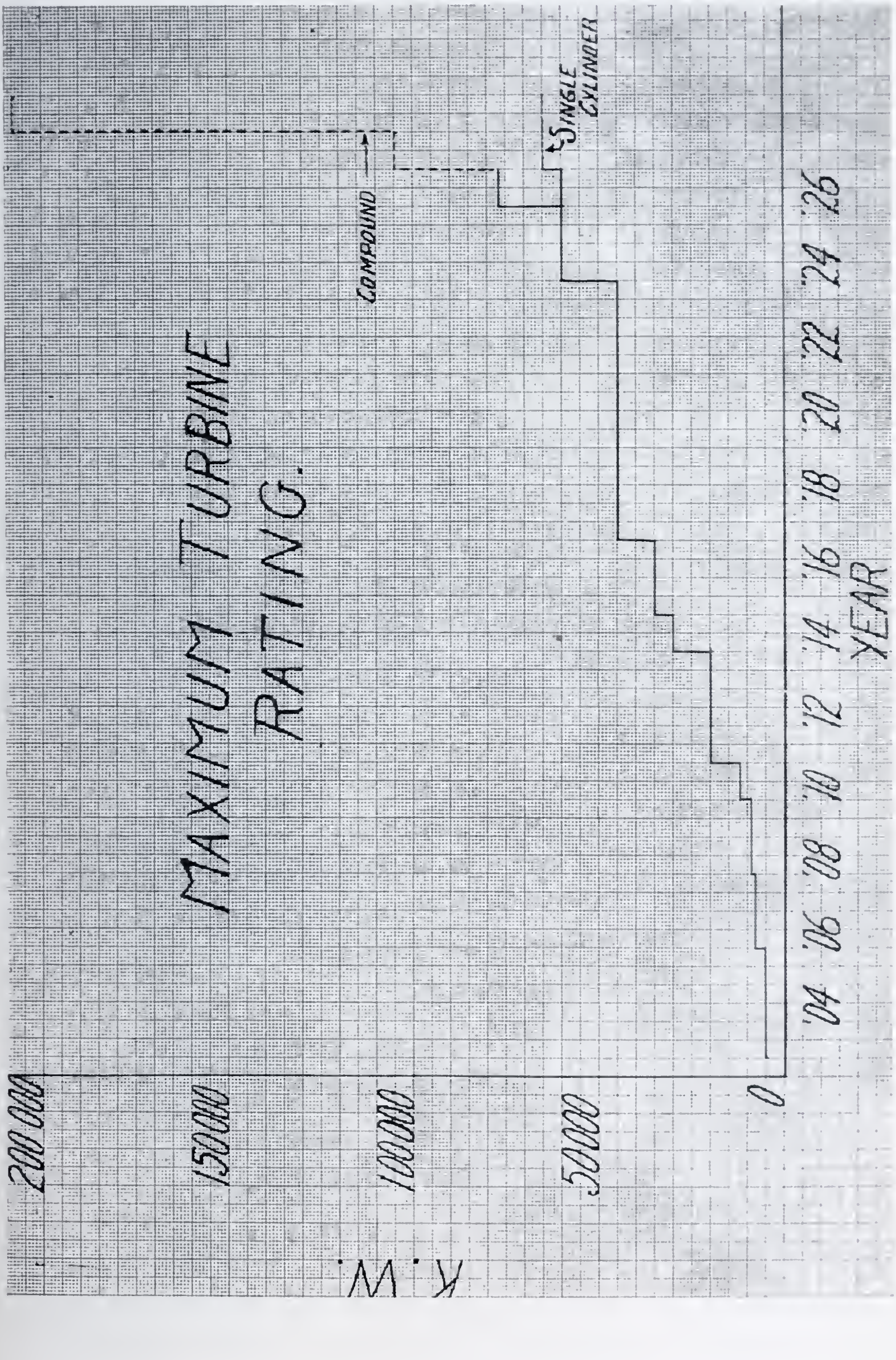

Fig. 1. Increase in Turbine Capacity.

tion on the shore of Lake Michigan. The station is to be the largest in the world, and the turbine generator will be the largest of any type.

The Southern California Edison Company is to install two tandem-compound turbines, rated at 94,000 kilowatts, at 90 per cent. power-factor, or 105,000 kilowatts at unity power-factor. These will be the largest tandem-compound turbines ever built and will drive the largest generators ever built for any type of steam-turbine.

The Edison Electric Illuminating Company of Boston is to install a 65,000-kilowatt, single-cylinder, turbo-generator. This machine will be the largest single-cylinder turbine in the world.

This tremendous increase in capacity has been made possible through engineering research; through the development and application of superior materials; and through the foresight and courage of officials of the central-station industry who had the faith to back their judgment, and the ability to develop the ever increasing use of electricity. A 208,000-kilowatt unit would have been useless as well as impossible a few years ago.

The fairly consistent increase in the initial steam *pressure* and *temperature* through this period is shown in Fig. 2 and 3; and the reduction in fuel consumption which has accompanied those developments is shown in Fig. 4.

This reduction in the heat rate chargeable to the turbines has, of course, been accompanied by improved efficiency in other power-house apparatus and by improvements in methods of operation. The use of units of larger capacity has also tended to hold down the capital charge per unit of installed capacity, so that, although even the largest turbine units to-day cost 50 per cent. more per unit of capacity than in the pre-war period, and in spite of increased costs for fuel, for labor, for material, and for all other equipment, the price changes for electricity as a commodity have been slightly downward in the face of greatly increased prices for almost all other commodities.

During this period cast-iron has been replaced by steel in turbine shells; and brass or bronze by steel, monel metal and stainless iron in turbine blades; heat-proof insulating material has been developed, and countless changes have been made in details and methods of manufacture. The illustrations which follow show the appearance and construction of some modern machines.

The Milwaukee Electric Railway and Light Company station at Milwaukee, Wisconsin, contains three 30,000-kilowatt and two 20,000-kilowatt, 60-cycle machines at 1800 r.p.m. There have been

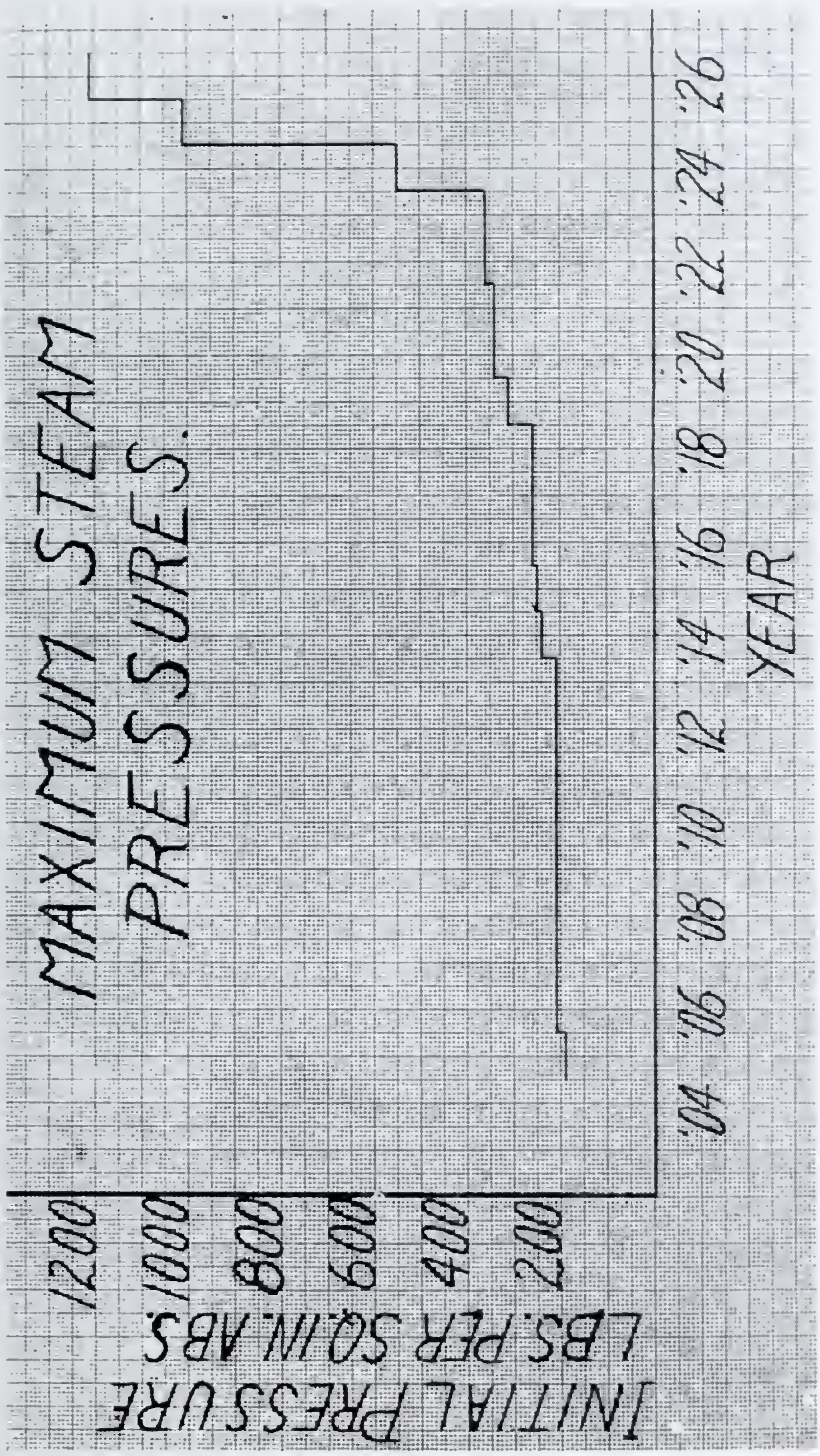

Fig. 2. Increase in Steam Pressure.

installed also a 30,000-kilowatt unit and a 7000-kilowatt, 1200-pound, high-pressure machine. It will be of interest to you to know that this is the first large central station to burn pulverized coal exclusively.

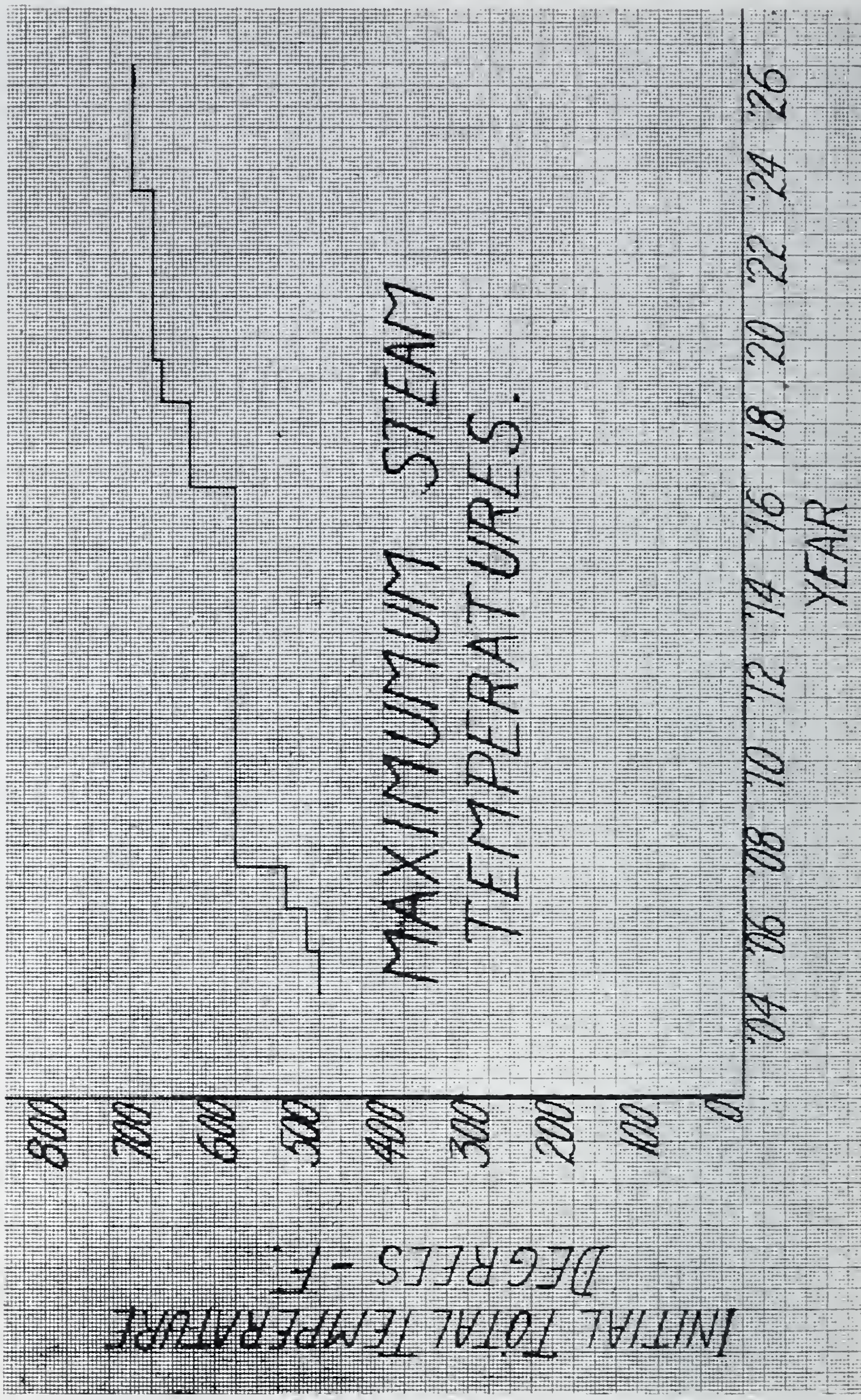

Fig. 3. Increase in Temperature.

Fig. 5 is a view of the 7000-kilowatt, high-pressure, 1200-pound unit at 3600 r.p.m. installed at Milwaukee. I will speak later about these high-pressure installations.

The Edgar Weymouth station of the Edison Electric Illuminating Company, Boston, contains two 30,000-kilowatt, 60-cycle,

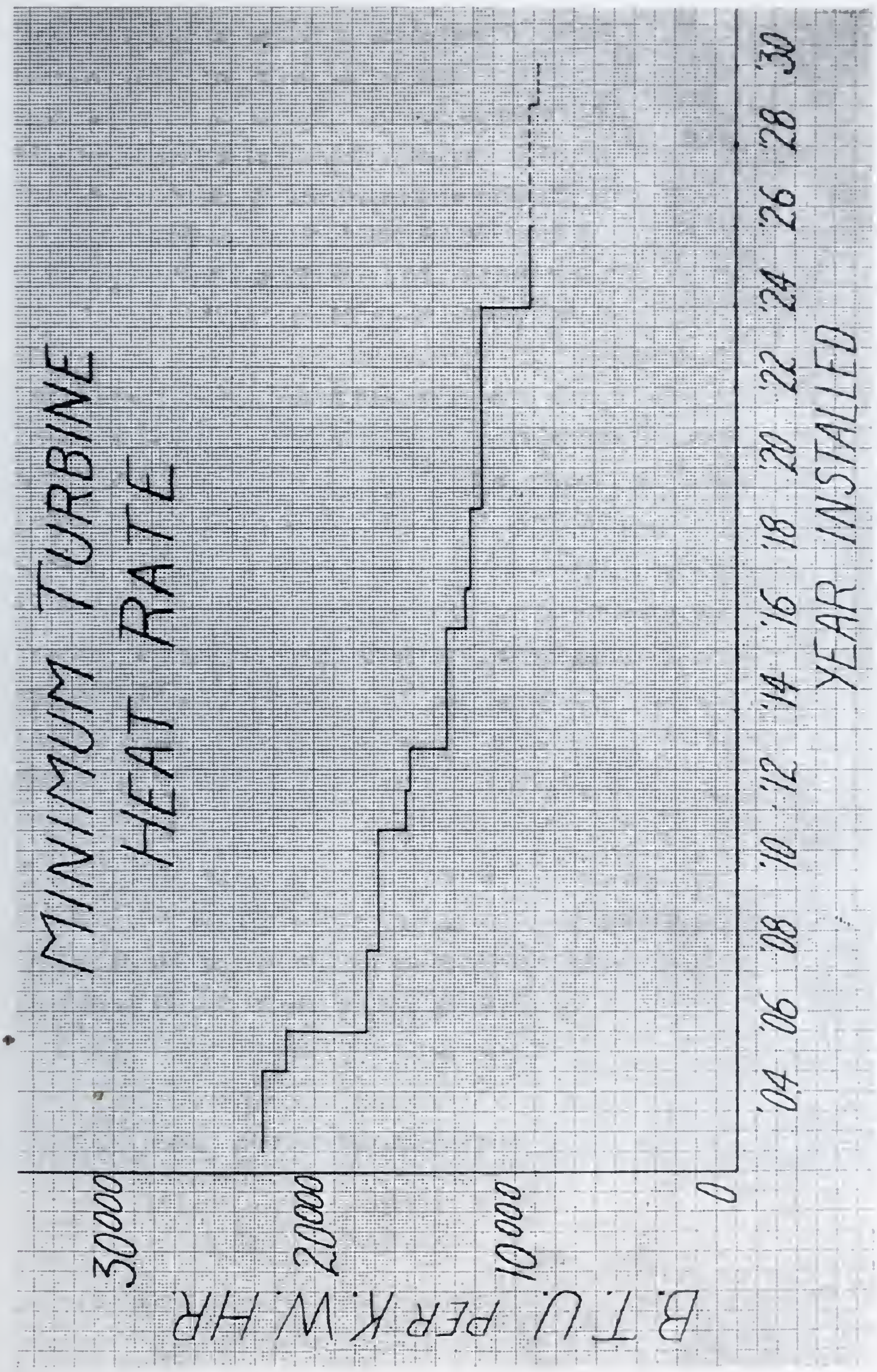

Fig. 4. Reduction in Fuel Consumption.

turbo-generator units at 1800 r.p.m., equipped with 2000-kilowatt service generators. This was the first installation in this country having service generators coupled to the main generator shaft for supplying power to the electrically driven auxiliaries. A 3000-kilowatt,

high-pressure, 1200-pound unit at 3600 r.p.m. has been installed in the Edgar Weymouth station.

The Long Beach station No. 2 of the Southern California Edison Company, Los Angeles, is supplied with an installation of two 35,000-kilowatt, 50-cycle turbo-generators at 1500 r.p.m., equipped with service generators. The first of these units was shipped within eight and a half months from receipt of order and put in regular commercial service in less than one year.

Fig. 6 shows the Philo station of the Ohio Power Company, with an installation of two 40,000-kilowatt, 60-cycle, single-casing,

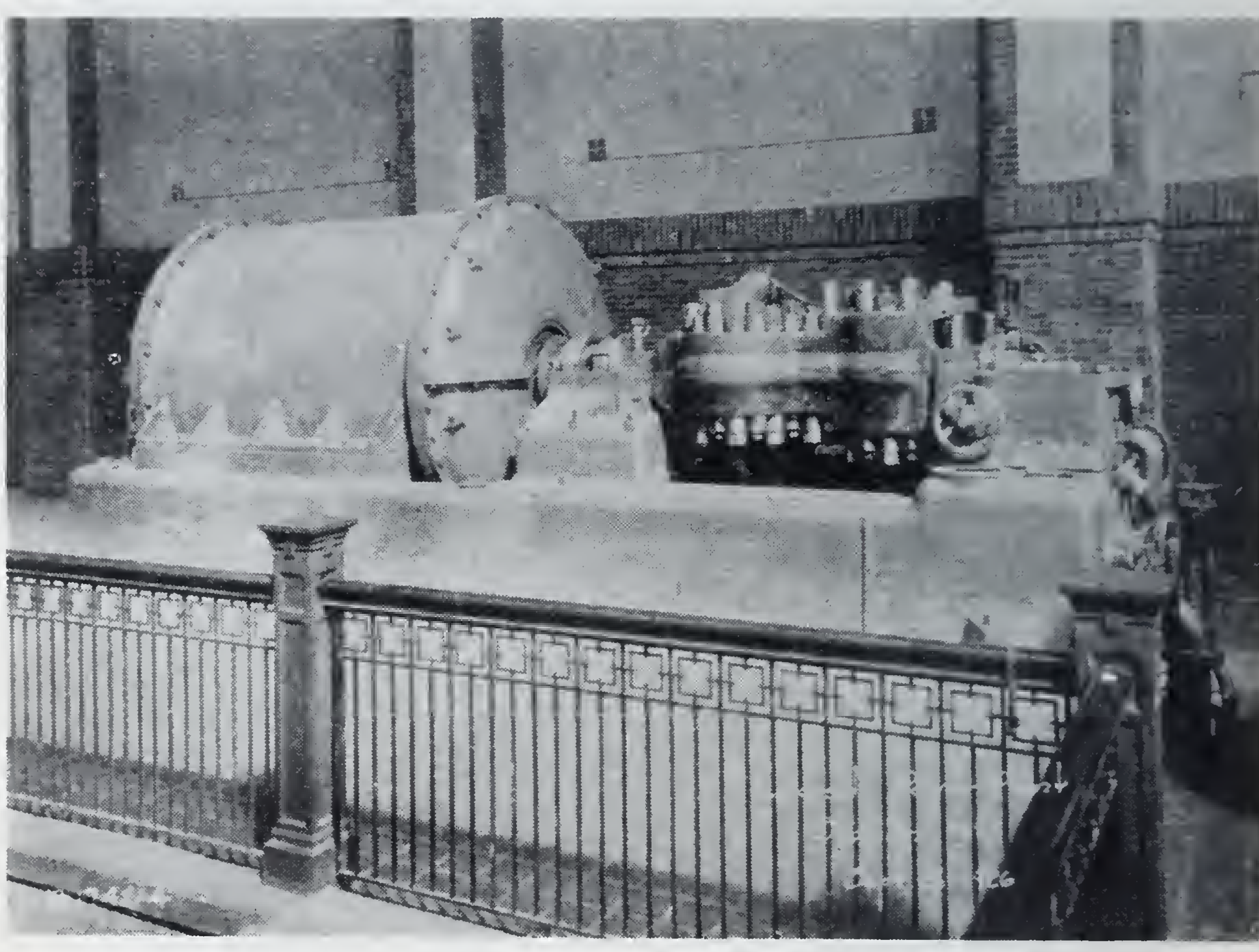

Fig. 5. High-Pressure, 7000-Kilowatt Unit.

reheat turbo-generator units at 1800 r.p.m. These turbines are operated at 600 pounds gage pressure, 725 degrees F. total temperature and one inch absolute back-pressure. After partial expansion, the steam passes through the reheat boiler and is again returned to the turbine at a temperature of 725 degrees F. and at a pressure of approximately 110 pounds absolute. This is the first large installation of 600 pounds pressure utilizing this reheat feature.

The Miami Fort station of the Columbia Power Company, Cincinnati, is furnished with two 45,000-kilowatt, tandem-compound turbine generators at 1800 r.p.m., equipped with service generators. These machines are to operate under a pressure of 600 pounds gage, at 725 degrees total temperature, and are arranged to reheat the steam between the high-pressure and low-pressure elements.

Three 50,000-kilowatt, 60-cycle, single-casing, no-reheat, turbo-generator units at 1200 r.p.m. were originally installed in the Trenton

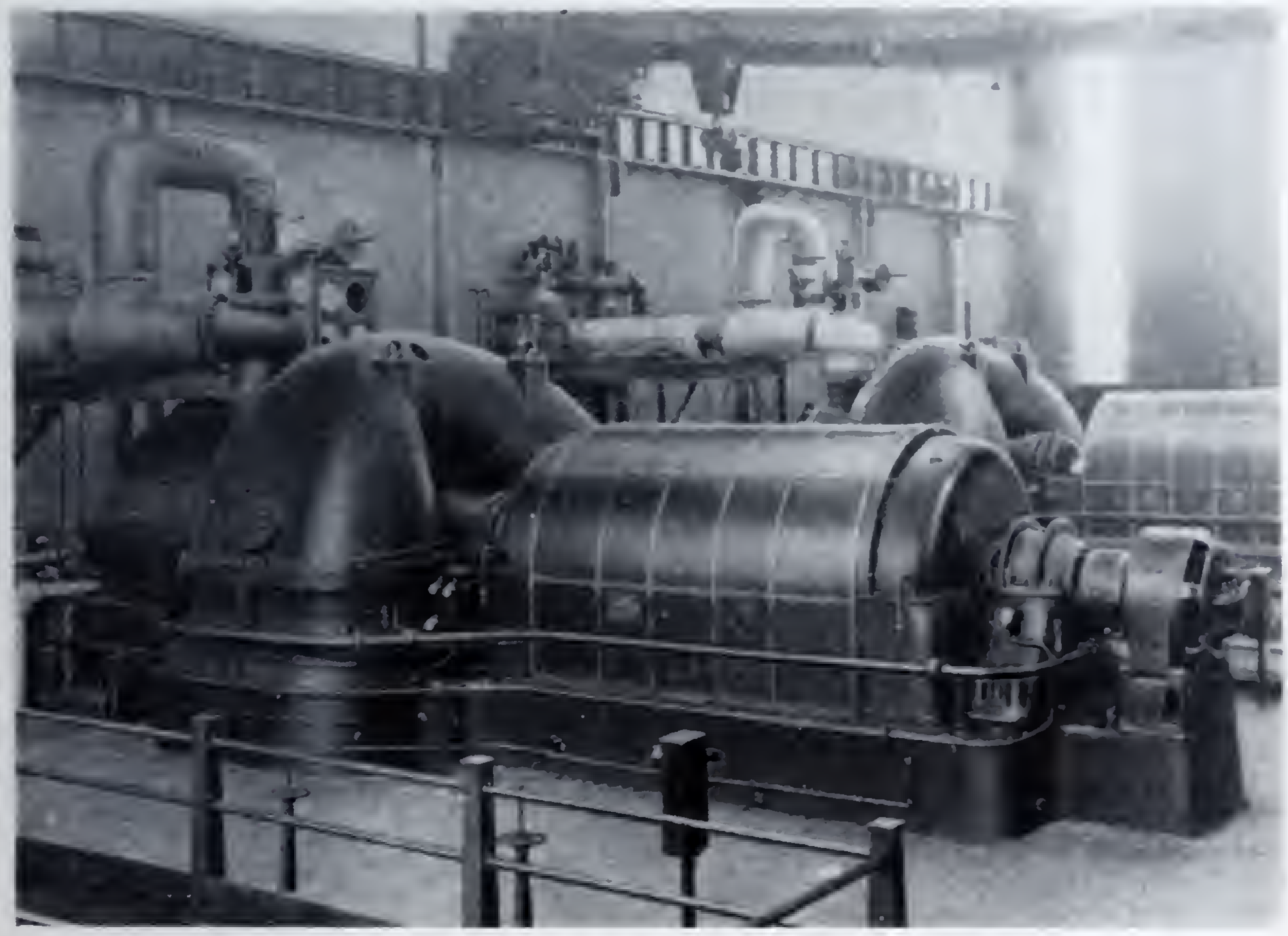

Fig. 6. Two 40,000-Kilowatt Curtis Turbine Generators.

Channel plant of the Detroit Edison Company. Subsequently, two duplicate machines were installed, and the sixth unit is now on order in the factory. These turbines operate under steam conditions of 375 pounds pressure and 700 degrees F. (251 degrees superheat) total temperature.

The New Richmond station of the Philadelphia Electric Company, Philadelphia, has an installation of two 50,000-kilowatt, tandem-compound turbine generators, of 62,500 kilovolt-amperes, and 1800 r.p.m.

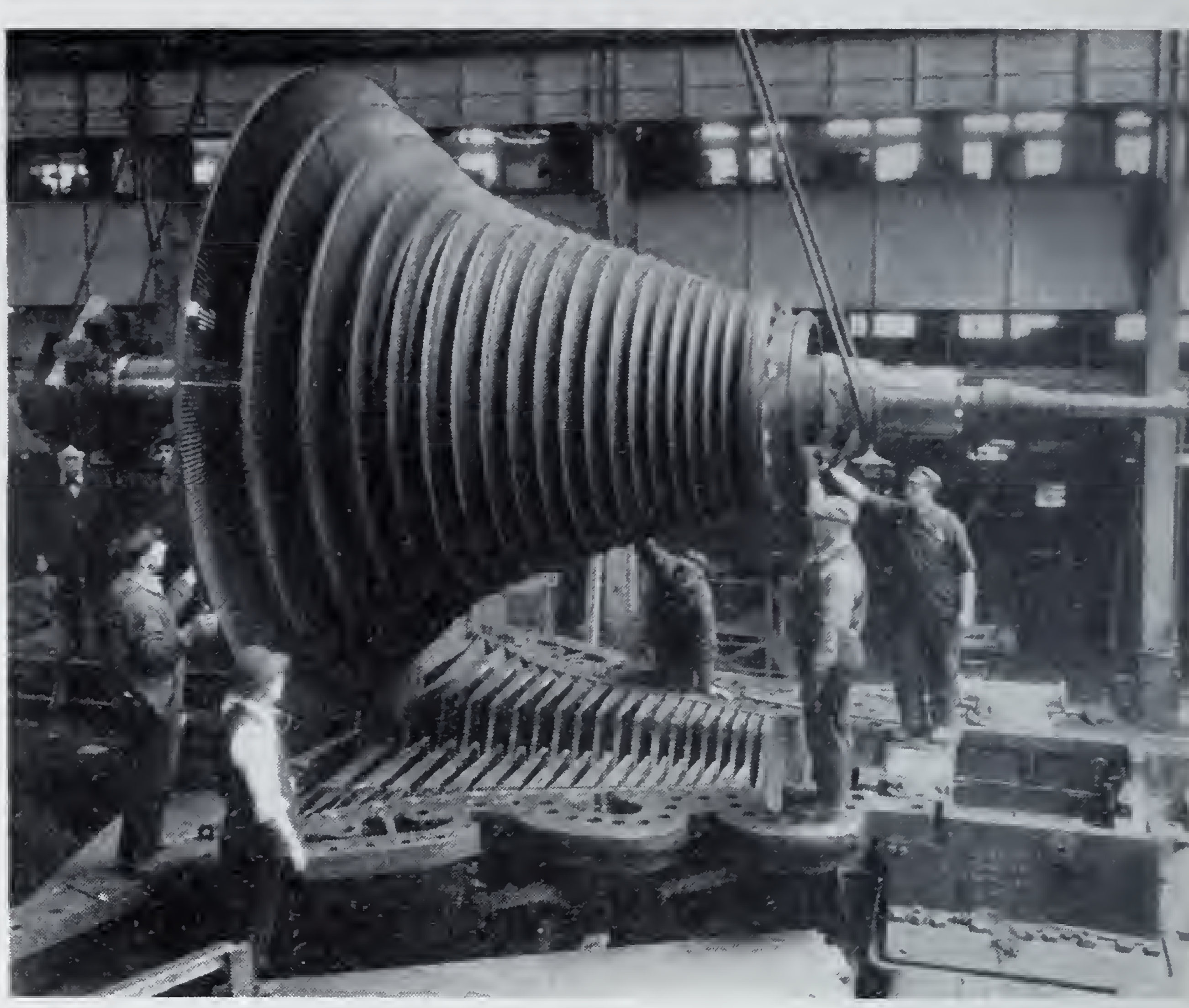

Fig. 7. Turbine Rotor of 60,000-Kilowatt Unit.

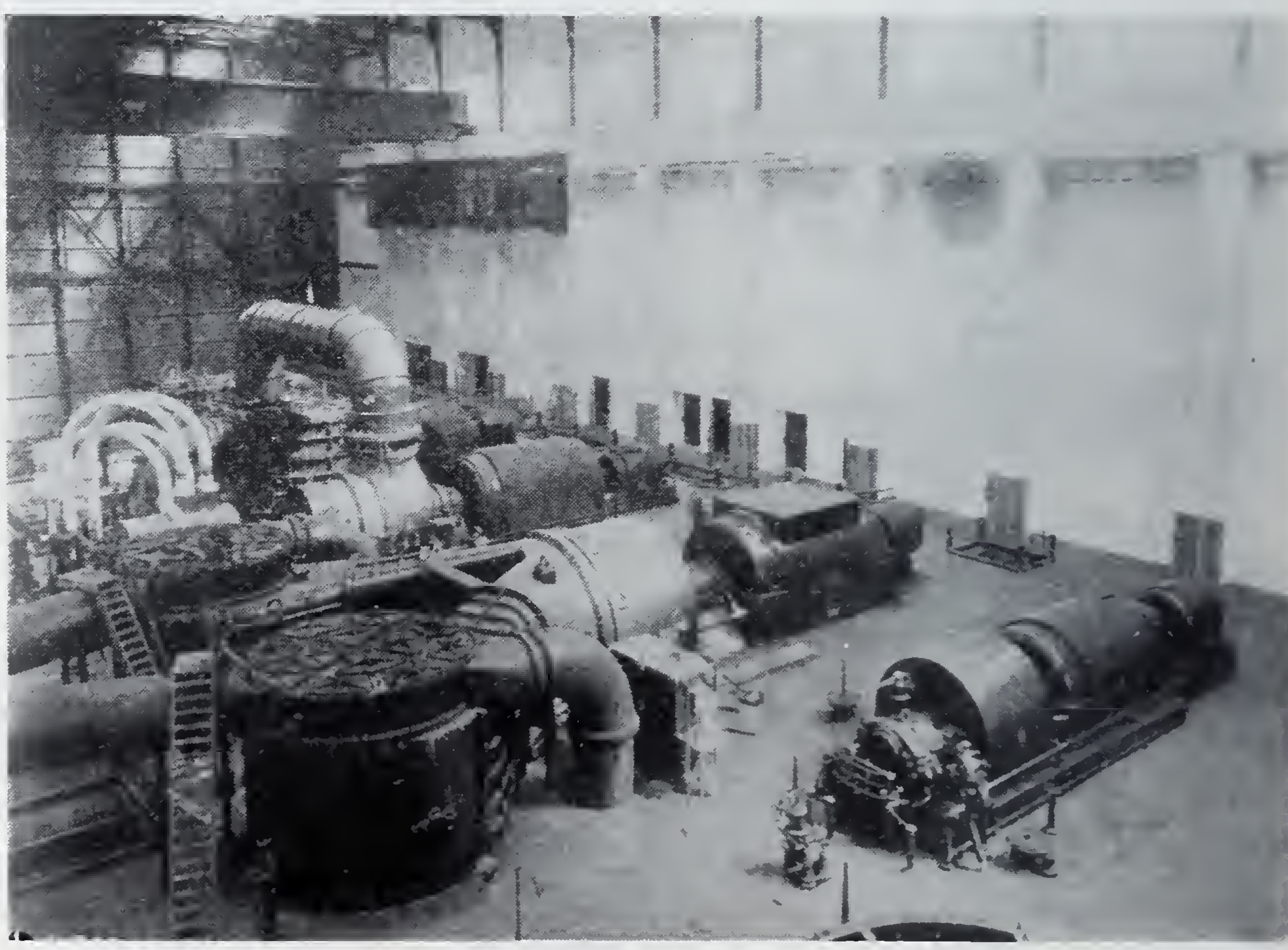

Fig. 8. Curtis 60,000-Kilowatt Compound Turbine Generator.

Fig. 7 is a view showing the assembly of the turbine rotor in one of the two 60,000-kilowatt, 25-cycle turbines at 1500 r.p.m. now installed in the East River station of the New York Edison Company.

Fig. 8 shows the Crawford Avenue station of the Commonwealth Edison Company, Chicago. It shows the 60,000-kilowatt, cross-compound, General Electric turbine, and in the distance the 50,000-kilowatt, cross-compound Westinghouse machine. The General Electric machine operates at 550 pounds pressure, and 725 degrees F. total temperature, and reheats between the high-pressure and low-pressure elements. Naturally many serious difficulties have been encountered and overcome during this development.

One outstanding development has been the research initiated by the late Wilfred Campbell into the prevention of resonant vibration of turbine wheels and buckets. This work has been covered by two papers before the American Society of Mechanical Engineers,*† so that detailed discussion would be out of place here. However, this work has made possible the long high-speed buckets required in large turbines and has established as routine factory production the testing of wheels in "steam boxes." In these "steam boxes" the resonant characteristics of wheels and buckets are determined by actual test at running speed before assembly in the rotor. It is only through such means that reasonable freedom from bucket failures can be assured.

Another development has been the reduction of eddy losses in turbine blades and nozzles through the turbine designers, as discussed in "An Experimental Investigation of Nozzle Efficiency" by H. Loring Wirt,‡ in 1924.

Such research development has resulted in five large stations operating to-day at pressures around 600 pounds, and two with 1200 pounds initial pressure at the turbine throttle. It seems reasonable to suppose that 600 pounds may become a common pressure and that 1200 pounds or some higher pressure will be used both in new stations and through the use of the so-called reducing-valve type of turbine to prolong the economic life of old stations.

The development of high-pressure apparatus can also reasonably be expected to result in the use of reducing-valve turbines as a means

*Protection of Steam-Turbine Disk Wheels from Axial Vibration, by Wilfred Campbell. Trans. A.S.M.E., v. 46, p. 31.

†Tangential Vibration of Steam-Turbine Buckets, by Wilfred Campbell. Trans. A.S.M.E., v. 47, p. 643.

‡Trans. A.S.M.E., v. 46, p. 981.

of producing the process steam required in many manufacturing industries.

No analysis of the trend of turbine development would be complete without reference to the "binary vapor cycle."

The experimental mercury boiler and turbine installed at Hartford have been so successful that the installation of several standard-

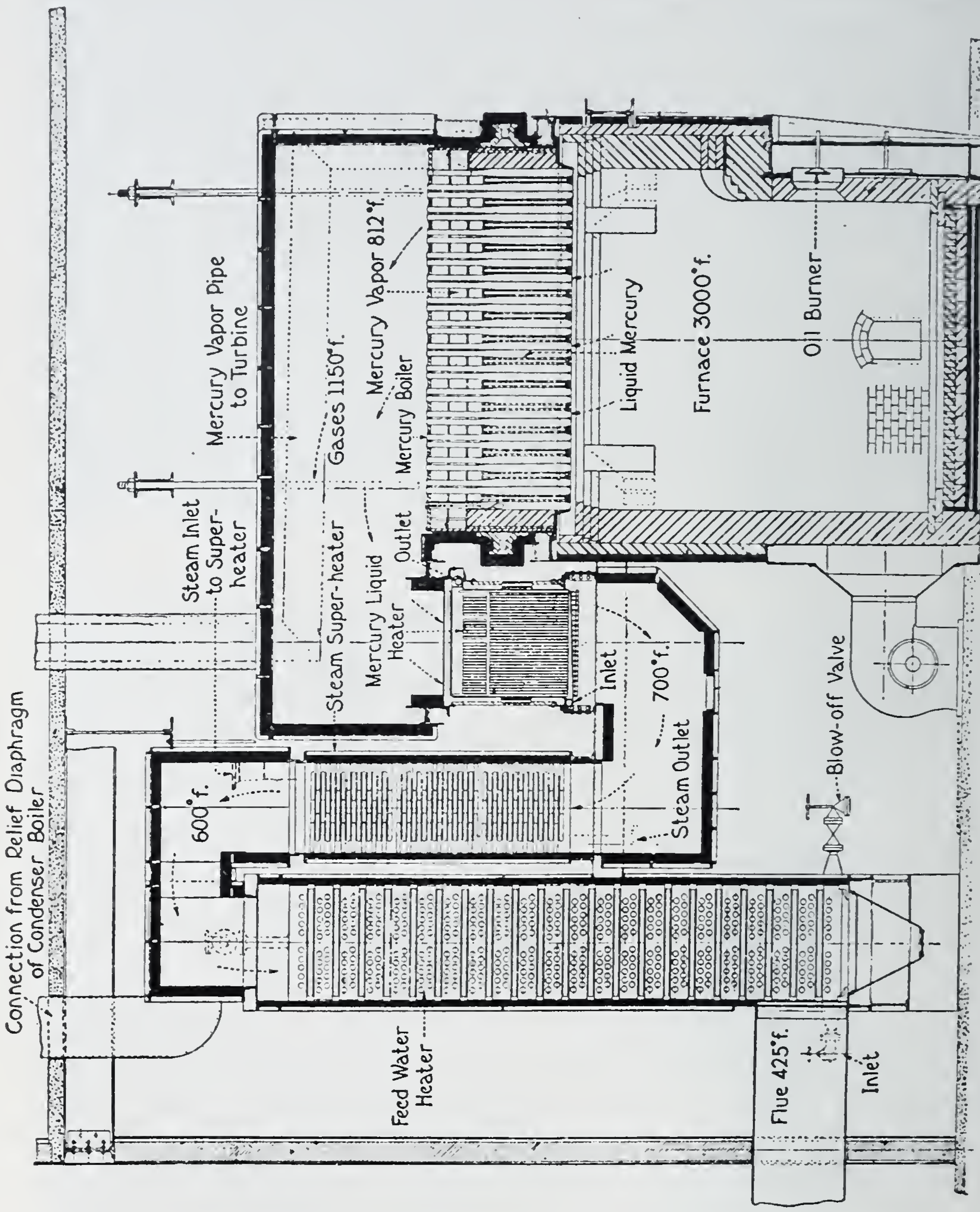

Fig 9. Section through Mercury Boiler, Heater, Superheater, and Feed-Water Heater.

ized commercial equipments of about 10,000-kilowatt capacity may be expected in the not far distant future. Fig. 9 and 10 show the mercury turbine, mercury boiler, and condenser. These figures are repro-

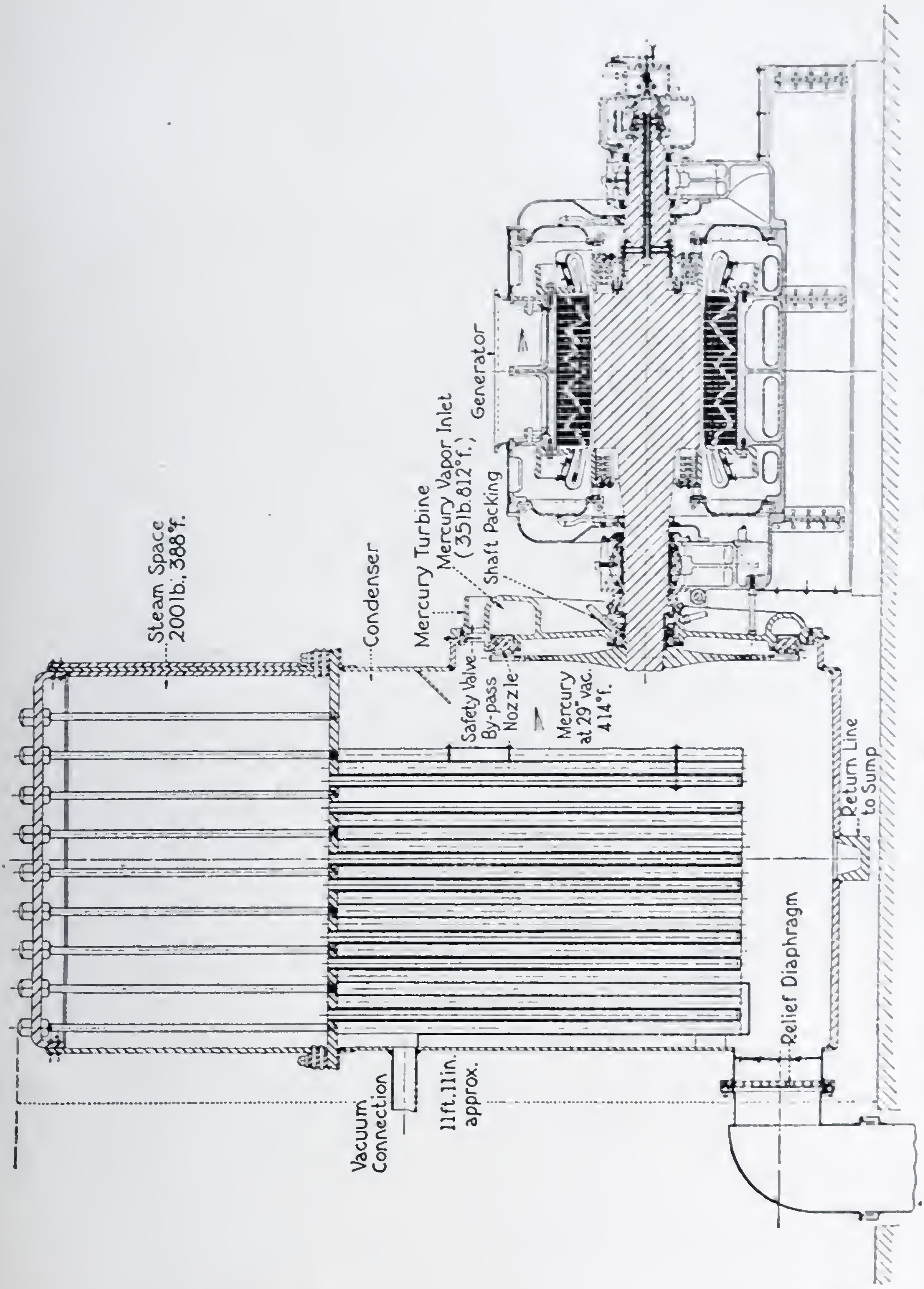

Fig. 10. Section through Mercury Condenser, Turbine, and Generator.

duced from a paper by W. L. R. Emmet, on "The Emmet Mercury-Vapor Process."*

In the future, steam units of still larger capacity will be built if, and when, the power-generating industry demands them. Units to

*Trans. A.S.M.E., v. 46, p. 253.

operate at higher temperatures and pressure will also be developed as the economic need arises. In some cases the binary vapor cycle will more completely meet the economic conditions.

Undoubtedly the cost of fuel will continue to increase, the use of electricity will continue to increase, the power-generating industry will continue to be far-sighted and courageous, and the manufacturers will do their part.

TRENDS IN TURBO-GENERATOR DEVELOPMENT*

By F. D. Newbury†

There is one aspect of this subject which has been referred to by the other speakers, but which I would like to develop a little further. It is the very rapid growth and development that has occurred during the past three years—a development that has been greatly accelerated, as compared with the development of the preceding eight or ten years. If you will recall Mr. Spellmire's curve showing increase in size of turbine generators by years, you will remember there was a horizontal line showing no increase in size between the years 1916 and 1923, and there was a great increase in size and a great increase in steam pressures during the three years since 1923. That is the point I would like to develop.

We are in the third decade of the commercial development of the steam-turbine and the turbo-generator. It is interesting to note that many of the men now actively connected with the turbine generator industry have been participants in, or at least witnesses of, this entire development. The first decade, roughly from 1900 to 1910, was the decade of type development. This is true of the development of almost any kind of apparatus. The early work is characterized by a wide variety of types. Different designers are working along radically different lines, and it is only as the development approaches a conclusion that these lines of development converge into one type. Until this occurs, one may justly question whether a final design has been achieved. So in the first decade we see a number of radically different lines of development. Emmet, Reist, Foster and others at Schenectady were developing the relatively low-speed, vertical-shaft type of turbine, pictures of which you have just seen. In general, these designs followed salient pole constructions modified to suit the higher speeds involved; that is, higher speeds from the standpoint of this type of construction. At the Westinghouse works, Lamme and Kingsbury were developing a high-speed, horizontal-shaft type of generator which, in the first decade, raeched a size of 10,000 kilowatts at

*Presented January 11, 1927. Received for publication March 15, 1927.

†Manager, Power Engineering Department, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.

1800 r.p.m. They developed the so-called parallel-slot, rotor-winding construction in which the windings were disposed in slots parallel to each other. The projecting-pole Maltese-cross-shaped rotor in the four-pole design and the cylindrical rotor in the two-pole design reached ultimate sizes of about 10,000 kilowatts at speeds of 1800 and 1500 r.p.m. for the two important commercial frequencies.

In Europe the principal designer was C. E. L. Brown—one of the founders of the Swiss Brown-Boveri Company and one of the outstanding designers of electrical machinery in the world. To him belongs the credit (at least for Europe) of originating the type that has persisted through these three decades of development. This is the so-called radial-slot rotor, and its associated windings in which the plane of every winding slot is radial, in distinction to the parallel relationship of the Lamme design. Brown also conceived and patented the parallel-slot arrangement of windings, but, so far as I have knowledge, did not develop this type commercially.

In this country Behrend, then Chief Engineer of the Bullock Company, paralleled the work of Brown in Switzerland and, in 1901, built the first modern type turbine generator in the United States, with cylindrical rotor, radial winding slots and chrome-nickel steel retaining rings to support the projecting coil ends. A 1000-kilowatt, 1500 r.p.m. unit of Behrend's design was exhibited at St. Louis in 1904. This radial-slot design type is the type that all builders, both here and abroad, are using to-day.

Early in the second decade, about 1912 or 1913, both types that had been under development in this country were abandoned because of the competition of better types. The vertical-shaft design was best adapted to a large-diameter, short, low-speed turbine and generator. With vertical shaft bearings then available the maintenance expense of a vertical unit was relatively high. The steam economy incident to high turbine speeds killed the vertical-shaft turbine.

The four-pole, Maltese-cross design required large castings of nickel steel of high quality which were difficult to obtain. Noise, caused by the projecting poles, was a minor cause of its abandonment. The two-pole, parallel-slot design did not have these particular limitations, but it suffered, in common with its four-pole brother, in having a more limited space for windings with a given rotor diameter, as compared with the radial-slot type. Rotor ampere turns constitute

an important factor in generator rating, and this limitation was a handicap the parallel-slot type could not overcome.

These are interesting examples of the "survival of the fittest" in the evolution of turbine generator types. Early in the second decade this evolution had resulted in the universal adoption of the radial-slot rotor and its associated winding, the horizontal shaft, and the completely enclosed turbine generator.

During the first half of this decade, sizes of generators at 1800 r.p.m. increased from 10,000 to 20,000 kilowatts almost over night. That great increase in capacity came about, as such increases often do, because these types of design had been proceeding along certain lines and had approached ultimate possibilities. Naturally, progress halted. Then a radically new type was employed. These old barriers disappeared and progress was greatly accelerated. This was the situation in 1911-1913. After this first rapid advance, further increases in size came more slowly. Sizes increased from 20,000 to 30,000 kilowatts during the three years from 1913 to 1916. Then, for more than five years, progress stopped. This brings us to the third year of the present decade, 1923, and the beginning of the rapid increase in size, and the rapid development of the turbine and generator that I mentioned in my opening remarks.

It is interesting to trace through a few particular installations how rapidly sizes increased about this time. Early in 1923 the Public Service Corporation of New Jersey started its Kearney station. In connection with the development of that station, 35,000-kilowatt units at 1800 r.p.m., and 80 per cent. power-factor (or 43,750 kilovolt-amperes), were offered by the Westinghouse Electric and Manufacturing Company for the first time by any manufacturer. This was the first important break from the 30,000-kilowatt unit of 1800 r.p.m. that had for a long time represented the maximum generator size at 1800 r.p.m.

In less than a year, or in February 1924, during negotiations in connection with the Richmond station of the Philadelphia Electric Company, units of 50,000 kilowatts (62,000 kilovolt-amperes) at 1800 r.p.m. were offered and contracted for by the General Electric Company. In a single year the maximum size generator that any company was willing to offer had increased from 43,750 to 62,000 kilovolt-amperes. This fact is to be contrasted with the situation for

the seven years from 1916 to 1923, when no company had been willing to consider units larger than 30,000 kilowatts at the speed of 1800 r.p.m.

Two years after the inauguration of the work on the Richmond station, in connection with the State Line station near Chicago, single generators of 75,000 kilowatts (94,000 kilovolt-amperes) were offered, and units only slightly smaller than that were actually purchased. So in another two years the maximum size increased from 62,000 to 94,000 kilovolt-amperes—a jump of 50 per cent. In three years, from 1923 to the present time, the maximum unit at 1800 r.p.m. has more than doubled in size.

It must not be forgotten that this discussion is limited to single generator units at 1800 r.p.m. Recent developments have made it possible to design four-pole generators of such large size that generators of lower speed (introducing very troublesome and expensive manufacturing and transportation problems incident to the weights involved) need scarcely be considered. There has been a parallel development of the cross-compound unit resulting in very large complete turbine generator units. The first 30,000-kilowatt, cross-compound unit—a Westinghouse design—was installed by the Interborough Company in New York in 1914, and the first 60,000-kilowatt cross-compound was installed by the Duquesne Light Company in the Colfax station in 1916. All of the recent record-breaking units (as to size) have been of the cross-compound type.

It may be interesting to refer to the reasons for the long halt from 1916 to 1923. In the first place, that period, it will be noted, included years of the World War, during which there was very little development of any kind not directly associated with the war. Also, during the earlier years of this period, many operators thought that a single generator unit of 30,000 kilowatts was as large a unit as should be installed in any station. Development was slowed up by a lack of demand, just as, during the past three years, development has been accelerated by the favorable attitude of operating engineers.

In addition to these external factors, there were also inherent design factors that slowed up the progress of the art. I can refer to this situation only as it affected Westinghouse practice with which I am familiar. In the practice of this Company, stator ventilation was,

at this time, one of the important design reasons for not increasing generator sizes above 30,000 kilowatts at 1800 r.p.m.

When I referred to the first period of development you will note that I mentioned only types of rotor construction. The generators were relatively small, as we now consider size, but speeds were so high as to engender a new design situation in which the principal problem was the mechanical engineering problem of rotor design. All of the generators of that early day employed the simple type of radial ventilation, which is familiar because of its use in practically all types of low-speed and moderate-speed machinery. In this simple radial scheme of ventilation, the air was supplied to the generator stator through the air-gap at the two ends of the generator. As generators increased in output without increase in diameter, a proportional increase in air volume was required with no larger area through which to supply that air. Ultimately the limits of this system were reached, and designers were forced to look for other methods of ventilation. During the development of 1912 and 1913 (during which the radial-slot rotor was adopted) Westinghouse engineers also adopted and developed the so-called axial system of ventilation, in which air-ducts, parallel to the air-gap, were constructed so that part of the air passed through the air-gap and part through these axial ducts.

This scheme obviously avoided the limitation embodied in the fixed air-gap area of the simple radial system and permitted the use of any desired air-duct area. Consequently, this system was characterized by large duct areas, low air velocities, and low windage losses. It possessed, however, the seeds of two defects which remained unimportant, in effects, until generators increased in size much beyond the sizes contemplated in 1912. In this system the cooling air does not come in direct contact with the armature coils, and the heat from the copper is transmitted to the core teeth and through the length of the teeth to the air-gap and to air-ducts back of the teeth. As slots increased in depth from four inches to eight inches, as they have during the past few years as generators have increased in size, the temperature drops in the teeth increased in even greater ratio. As core lengths increased from 60 inches (which was a long core in 1912) to 100 inches (in 1916) and now to more than 200 inches, the increase in cooling-air temperature along the length of the axial ducts became a serious factor. Here is another illustration of a design

type which possessed controlling advantages under the conditions existing at the time of its introduction, but which failed to meet the changing conditions of its environment and, consequently, was superseded by a type better adapted to these new conditions. As core lengths increased and slot depths increased (with the demand for larger and still larger generators) a new type of ventilation was required.

Other designers had not abandoned the radial system of ventilation when the simple type failed to meet the needs of the turbine generator. It has been pointed out that the serious limitation of the simple radial cooling system was found in the limited entrance areas provided by the air-gap, as these remained constant while air requirements increased practically in the ratio of the generator rating. To meet these conflicting requirements, air velocities in the simple system were increased to values up to 10,000 feet a minute (with air particles traveling faster than the fastest airplane) and windage losses became the major loss in the generator. The first important improvement in the simple radial system made in this country was by Holcombe of the General Electric Company, who applied to turbine generators in 1918 a construction originated by the Oerlikon Works of Switzerland in 1906. This was the use of an additional inlet chamber in the center of the core, which added considerably to the inlet area afforded by the simple radial system. In the General Electric construction, two air-pressure chambers at each end of the generator were provided, each with its separate fan (four to each generator). One pair of fans and air-pressure chambers supplied air to the air-duct entrances as in the simple system, and the second pair supplied air (at a different pressure, if desired) to the outer surface of the core at the center of the length of the generator. This improvement considerably extended the successful application of the radial system, but it also failed to meet the ever-increasing demands for larger generators, and included the undesirable complications of double-pressure chamber and fans.

In 1920, Westinghouse engineers recognized the limitations of the axial system and of the other systems then in use, and undertook a comprehensive experimental investigation of turbine generator ventilation by means of full-size rotating models. Later, in the investigation, it was found possible to duplicate actual generator conditions by employing stationary models representing only one longitudinal plane

section of the generator. Extensions of this first investigation are still in progress.

This experimental work, conducted by C. J. Fechheimer, developed means by which the advantages of the simple radial system of ventilation can be obtained with a core of any length. By determining the necessary experimental data for calculations, the generator core can be designed (from the standpoint of air supply) with any desired number of sections, each receiving an independent supply of cooling air from a single pressure chamber and with a single fan at each end of the stator. The radial system of ventilation has been carried to its logical form, and, I believe, its ultimate stage, in which any desired number of parallel air paths can be provided. Ventilation is no longer influenced by length of core, and this obstacle to design has been removed.

Another important factor in the rapid increase in maximum ratings that has occurred during the past three or four years has been the improved rotor materials and constructions that have become available. Until 1924 the largest rotor diameter in use for generators at 1800 r.p.m. was 51 inches. The largest machines now being designed at 1800 r.p.m.—those approaching 100,000 kilovolt-amperes in single generator rating—have rotor diameters of 55 or 56 inches. This increase of about 10 per cent. may not appear important, yet it has made it desirable, and in some parts necessary, to employ new materials and new constructions throughout the rotor. The field-winding insulation will serve to illustrate this point. In the smaller generators, built-up mica is used to insulate the internal surface of the retaining rings from the projecting field coils. This insulation is subjected to a pressure (caused by centrifugal action) of 3000 pounds per square inch, and there is a longitudinal movement of the coil ends of roughly 1/16 inch caused by heating and cooling of the winding. With the larger rotor diameter of 56 inches, and with the deeper coils required by the larger generator rating, the unit pressure becomes 4000 pounds instead of 3000 pounds and the longitudinal expansion and contraction of the field winding is increased as the rotor length is increased. You can readily imagine that this combination of pressure and movement is destructive to insulating materials, and particularly so in the case of materials, such as built-up mica, that are readily abraded. Before this change in rotor diameter could be safely made,

a new rotor insulation had to be developed. This was found in an asbestos-bakelite molded material applied both to the internal surface of the retaining ring and to the outside surfaces of the projecting coil ends. The principal advantages of this material are its resistance to abrasion, as compared with mica, and its adaptability to molding into complicated shapes with the necessarily small manufacturing tolerances that are permissible. A measure of the relative life of this new insulation and the older mica insulation was obtained by devising a stationary model to duplicate operating conditions for one coil. With the new insulation, 1500 heating and cooling cycles (approximating the effects of starting and stopping) produced no effect on the insulation; with mica insulation tested in the same way 350 cycles destroyed the insulation.

Westinghouse engineers consider this new rotor insulation to constitute the most important advance in rotor insulation since the application of mica to slot insulation twenty years ago.

This is only one of a number of important design improvements that were necessary before generators larger than 50,000 kilovolt-amperes at 1800 r.p.m. could be safely undertaken.

DISCUSSION

G. S. HUMPHREY:* It would be interesting to hear just what it is that has been limiting the maximum capacity of machines that can be built on one shaft. Is it the turbine, or the generator; or has it been one at one time and the other at another time? We might also have a statement as to just what was necessary in the way of changes in design as the size of the steam units has increased. Was it just a question of taking the first ones made and making them longer and of larger diameter, or were fundamental changes in design necessary to get the higher capacities?

W. B. SPELLMIRE:† Mr. Newbury has touched on the question of ventilation as one of paramount importance. Not only ventilation, but the flow of gases, whether air or steam, whether ventilation in the rotor or stator, or the flow of steam in turbine nozzles, or around the blades, or in exhaust chambers, is a matter of great impor-

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†Manager, General Electric Co., Pittsburgh.

tance with respect to resistance encountered. When Dr. Whitney spoke before this Society, on December 14, 1926, he showed how a research department was inclined to challenge every unproved statement. He further showed that some things which seem axiomatic, when put to the proof show contrary results. In my brief paper I referred to the investigation conducted by Mr. Wirt in connection with wind tunnels, which leads up to a point which I was prepared to illustrate, but did not. In the past it has been customary to assume that when a certain ventilating scheme was put into effect—on a turbine rotor, for example—the air must flow in the direction in which we planned it to flow. Investigation by Mr. Wirt showed that many previous assumptions were in error. To illustrate Mr. Wirt's investigation, let us consider the inside of the exhaust end of a steam-turbine casing. It was painted with a mixture of oil and lampblack—a mixture which would not dry out quickly. Fluid was then passed through the casing and the whirls and eddies actually taking place were recorded on the lampblack mixture and impressions taken from this record by means of plaster of Paris. The negative thus obtained was studied.

Results of similar experiments showed that a gaseous fluid passing through a pipe with a sharp right-angle bend met with less resistance than a fluid passing, under the same pressure and density, through the same size of pipe with a curved bend, this being contrary to all assumptions. However, if vanes were placed in the curved right-angle bend then the resistance was tremendously reduced. The resistance to the flow in the three cases illustrated was in the order of magnitude of 5, 6, and 1.

Answering Mr. Humphrey's question as to the limiting factor in the size of turbo-generators, it may seem odd that this question backs us up to our friends in the manufacturing of steel. The size of forging which it is physically possible to produce is a limiting factor in production of large turbines. When forging presses are available to make larger forgings, then larger turbines in single units can be produced.

CO-OPERATIVE RESEARCH IN FERROUS METALLURGY AND THE PROBLEM OF INCLUSIONS IN STEEL*

By A. C. Fieldner†

THE CO-OPERATING INSTITUTIONS CONCERNED

The word "co-operation" is often regarded with suspicion because it is sometimes used to lend weight to the efforts of one particular group by giving the impression that the project in question has more general support and covers wider interests than is really the case. That this situation does not prevail with respect to the subject of my address will become evident as I relate the development and present status of the co-operation among the United States Bureau of Mines, the Carnegie Institute of Technology, and the iron and steel industry as represented by the Metallurgical Advisory Board, and which I will refer to respectively as the Bureau, the Institute, and the Advisory Board. You will find that each of the three parties to this co-operation is playing an active part and is fulfilling a particular function different from that of the other members of the triumvirate. Briefly, these three functions are education, research, and industrial application.

Function of the Carnegie Institute of Technology. The Institute provides to graduate students advanced training in the scientific principles of metallurgy, and holds the research fellowships under this co-operative plan, and on successful completion of their studies and the research problems grants them the degree of Master of Science. Not less than four fellowships are provided each year. These post-graduate students have thus had one year of advanced and special training in metallurgical research, fitting them for positions in the research and development departments of the steel industry. There is a rapidly growing demand for men with this special training.

The personnel and laboratories of the Institute are an integral part of the co-operative plan.

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†Superintendent, Pittsburgh Experiment Station, and Chief Chemist, U. S. Bureau of Mines.

Function of the United States Bureau of Mines. The research work of the fellowship men is done in the metallurgical laboratories of the Pittsburgh Experiment Station of the Bureau, under the immediate direction of members of the Bureau's staff. The Bureau provides laboratory facilities and a staff of experienced research metallurgists to guide the fellowship work.

Function of the Metallurgical Advisory Board. The Advisory Board, composed of metallurgists and executives from the industry, advises on the formulation of the research program, the selection of problems, the conduct of the research work, and carrying over into practice or industrial operations the results obtained. As a matter of fact, the Advisory Board has gone further and has given financial support for additional fellowships and a research metallurgical engineer.

Unique Advantages of This Combination. In no other place in the United States could this advantageous co-operation be carried on. In Pittsburgh we have a large, well equipped Experiment Station devoted to research in coal, coke, iron, and steel; an Institute of Technology with a strong Department of Metallurgy and the underlying sciences of metallurgical engineering; and the largest center of the iron and steel industries in the world. The Bureau's Experiment Station and the Institute are on adjoining properties and in close proximity to the Carnegie Library of Pittsburgh, one of the best reference libraries in the country, which regularly receives 600 technical journals and has 70,000 reference volumes on scientific subjects. The researches of the laboratory can be carried into the plants of the district without loss of time. Through the Advisory Board the plants are available to the research workers for full-scale experimentation, as are the Institute and Bureau laboratories open to the industries for co-operative investigations.

History of the Co-Operative Metallurgical Research. The first steps toward the organization of co-operative research in ferrous metallurgy were taken in 1923, when the Bureau agreed to establish a section thereon at its Pittsburgh Experiment Station and install a well equipped electric-furnace laboratory; and the Institute agreed to furnish four fellowships to work with the Bureau's staff on research problems. At the same time an Advisory Board of 25 members representing the iron and steel industry was organized. In the following

year, 1924, the electric-furnace and metallurgical laboratories at the Bureau were completed and the first four fellowships started work in August—two on a "Survey of Service Conditions of Open-Hearth Refractories"; two on "Boiler-Water Conditioning and its Relation to the Non-Condensable Gases in the Steam"; and one on "The Effect of Phosphorus on the Resistance of Low-Carbon Steel to Repeated Alternating Stresses."

In the following year the research on open-hearth refractories was continued by two other fellows; a fellowship was established on "Corrosion in Steam Boilers"; and another fellowship on "Case-Carburized Steel" was undertaken. The results of most of this research have been published in bulletins of the Institute. Even at this early date the Advisory Board took it upon itself to give financial support to some of the fellowships, so that financial support was given by all three parties to the agreement. The Bureau paid the salaries of the senior investigators of its staff and the maintenance of the laboratories; also, in the first problem undertaken—the "Survey of Service Conditions of Open-Hearth Refractories"—virtually all of the work was done in steel plants of the Pittsburgh district, where whole-hearted co-operation was extended by the plant managements.

During the progress of the second year's work it became evident that this co-operative scheme of research was eminently practicable and fulfilled a real need. It further appeared desirable to undertake a broad program of fundamental research in the science of steel making which would be of the greatest possible value to the industry as a whole. A special committee of the Advisory Board was appointed to consider and recommend an extended research program. This report, submitted early in 1926, recommended that "a study should be undertaken of the non-metallic inclusions in steel with particular reference to the underlying physico-chemical action in the open-hearth process which determines the amount and nature of these inclusions"; in other words, a study to determine the conditions responsible for what is known as "dirty" steel. The solution of this problem is of advantage to all steel companies and they should share the cost jointly. Furthermore, the joint co-operation of a number of plants having somewhat different conditions, with a research organization manned by scientists thoroughly grounded in physics, chemistry, and metallurgy is the combination best adapted for this type of research work, in which theory and practice must be closely correlated.

STUDY OF NON-METALLIC INCLUSIONS

The three parties to the co-operative agreement accepted the recommendations of the Research Committee of the Advisory Board, and Dr. Charles H. Herty, Jr., was detailed by the Bureau to give his entire time to this problem. He is a graduate of the University of North Carolina and the Massachusetts Institute of Technology, and prior to coming with the Bureau had several years' experience in practical open-hearth research at the Lackawanna Works of the Bethlehem Steel Company, at Buffalo. With the advice of the Research Committee he worked out the following five-year program for research, which it was estimated would require an annual contribution of $10,000 from the industry, in addition to the support already assured from the Institute and the Bureau.

PROGRAM PREPARED BY DR. C. H. HERTY, JR.

I. Survey of the literature on the subject.

   A. Types of inclusions.

      1. Oxids.
      2. Mixed oxids (ferrous silicate, etc.).
      3. Sulphids.
      4. Slag proper.
      5. Gases.
      6. Nitrides.

   B. Identification of the inclusions.

      1. Microscopic.
      2. Chemical.
      3. X-ray.

   C. Origin of the inclusions.

   D. Elimination of the inclusions.

II. Preparation of the inclusions in the induction furnace, with controlled additions of materials to pure iron.

   A. Ferrous oxid.

      1. Determination of the solubility of FeO in iron under a slag of 100 per cent. FeO, and the effect of temperature (quantitative) on the solubility.

a. Determination by the Ledebur method.
b. Determination by the vacuum-fusion method.

2. Study of the diagram FeO-Fe from the samples obtained in the work above.
3. Physical tests on samples taken from 1 above.
4. Determination of distribution ratio of FeO between slag and metal.

   a. From synthetic slags.

      1. The system FeO-CaO over pure iron.
      2. The system FeO-SiO_2 over pure iron.
      3. The system FeO-CaO-SiO_2 over pure iron.
      4. Other combinations.

   b. From analyses of steel and slag taken from open-hearth furnaces.

      1. For finishing conditions on different heats.
      2. For other points of equilibrium on different heats, lime boil, etc.
      3. Complete analysis on at least one heat.

   c. Open-hearth slags remelted in the induction furnace over pure iron. Here the effect of temperature may be studied for any given type of slag. (If the ratio of FeO in the slag to FeO in the steel is the same for open-hearth slag as it is for a slag of pure FeO this will show that the FeO in open-hearth slags is simply dissolved. If the ratio is different, one of two courses could be taken.)

      1. If the variation was regular it could be assumed that a definite portion of the FeO was in solution according to the law of distribution in dilute solution.
      2. If the variation was irregular the data would be the basis for a study of the behavior of FeO in slags of different composition.

5. Behavior of FeO in steel in the open hearth under different conditions.

a. Melting down—before addition of hot metal.
b. Immediately after ore addition.
c. Immediately after addition of hot metal.

B. Formation and identification of inclusions of which the base is FeO. Inclusions formed from:

1. Manganese.
2. Silicon.
3. Aluminum.
4. Other deoxidizers such as zirconium and titanium.

All these inclusions should be studied from the viewpoint of "type of inclusion," "size of inclusion," and "effect of inclusion on physical properties of steel." The methods of identification will necessarily depend upon the best results shown in the survey of the literature, combined with original work on method.

III. Elimination of inclusions.

A. In induction furnace with synthetic inclusions.

B. In open-hearth furnace.

1. Effect of size of particle and its progressive coalescence in the metal.
2. Effect of temperature, which will also cover effect of fluidity of the iron.
3. Effect of agitation in determining coalescence of particles and speed of elimination.
4. Effect of composition of slag.
5. Effect of viscosity of slag.

C. Methods to be used in induction furnace.

1. Inclusions formed as under II B.
2. Boil produced in the metal, and samples taken out at definite intervals.
3. Samples examined under the microscope, and X-ray and chemical analysis made.

D. Methods to be used in the open hearth.

1. Inclusions formed by:

a. Addition of hot metal to a heat low in carbon.
b. Usual practice in recarburizing with hot metal.
c. Usual practice in deoxidizing in the furnace, ladle, or molds.
d. Ore additions.

2. Samples taken as often as practicable after additions and examined as in C above.
3. For recarburizer practice, samples of the finished product taken and the inclusions determined therein, and the effect of these inclusions on the rolling or physical properties of:

a. The heat in question.
b. The test-pieces taken.

IV. Study of the viscosity of open-hearth slags.

A. Following the method of Feild and Royster.

1. Synthetic slags.
2. Open-hearth slags.

B. By "inclined-plane" method used by Herty in connection with work at open-hearth furnaces. This method consists briefly in allowing a known amount of liquid slag to flow down an inclined plane of known slope. The more viscous the slag, the more slowly it will run down the plane, and the thicker will be the layer of slag built up on the plane at solidification. The measurement of the thickness of the slag on the plane has been used as a measure of the relative viscosities of the slags tested.

PROBLEMS SELECTED FOR FIRST YEAR

Five problems have been selected for immediate consideration. These are outlined below.

1. Solubility of FeO with testing of the samples obtained (1, 2, and 3 under section II A).
2. Distribution ratio of FeO between slag and metal (4*a* under section II A).
3. Formation and identification of inclusions (section II B).
4. Elimination of inclusions (section III B).
5. Viscosity of synthetic open-hearth slags (section IV A).

(In studying the effect of slag viscosity on elimination of inclusions in the open hearth, it will be necessary to use some such method as that described above, as the investigation of viscosity of slags of synthetic origin will necessarily take considerable time before it can be used to predict viscosities of working slags.)

The basis of almost all the non-metallic inclusions in steel is FeO. It is, therefore, necessary to extend our knowledge of the action of this compound in iron as far as possible at the very outset of the program. For this reason the first two problems deal with the properties of FeO in steel and slag.

One of the most important steps in the program is the identification of the various inclusions, qualitative and quantitative. For this reason, problem 3 has been chosen alone instead of combining it with section III A, the elimination of inclusions in the induction furnace. It is felt that this problem of identification is too large to be combined with another at the start of the work.

Problem 4, the elimination of inclusions in open-hearth practice, has been suggested, as it is believed that a great deal of information of value to the steel-maker can be obtained without relying too much on the fundamental work of section III A. Furthermore, it is believed that one problem of direct practical interest should be in progress at all times in order to make the contact between the plants and the laboratory continuous.

Inasmuch as open-hearth slags contain a large number of components, a large amount of work is necessary to determine the viscosity relations in these slags. Problem 5, the viscosity of synthetic open-hearth slags, is suggested because work on this subject must begin as early as possible in the program.

Research Organization. Fig. 1 shows the organization chart and the staff recommended by the Research Committee. It consists of the physical chemist in charge, an assistant physical chemist on laboratory research, an assistant metallurgical engineer for plant research, two analytical chemists, and five research fellows.

The organization of the research staff and the subscription of the necessary funds from the industry proceeded simultaneously during the summer of 1926, and by the beginning of the collegiate year the staff was completed and at work. The support from the industry was

PHYSICAL CHEMISTRY OF STEEL MAKING

STUDY OF THE NON-METALLIC INCLUSIONS IN STEEL

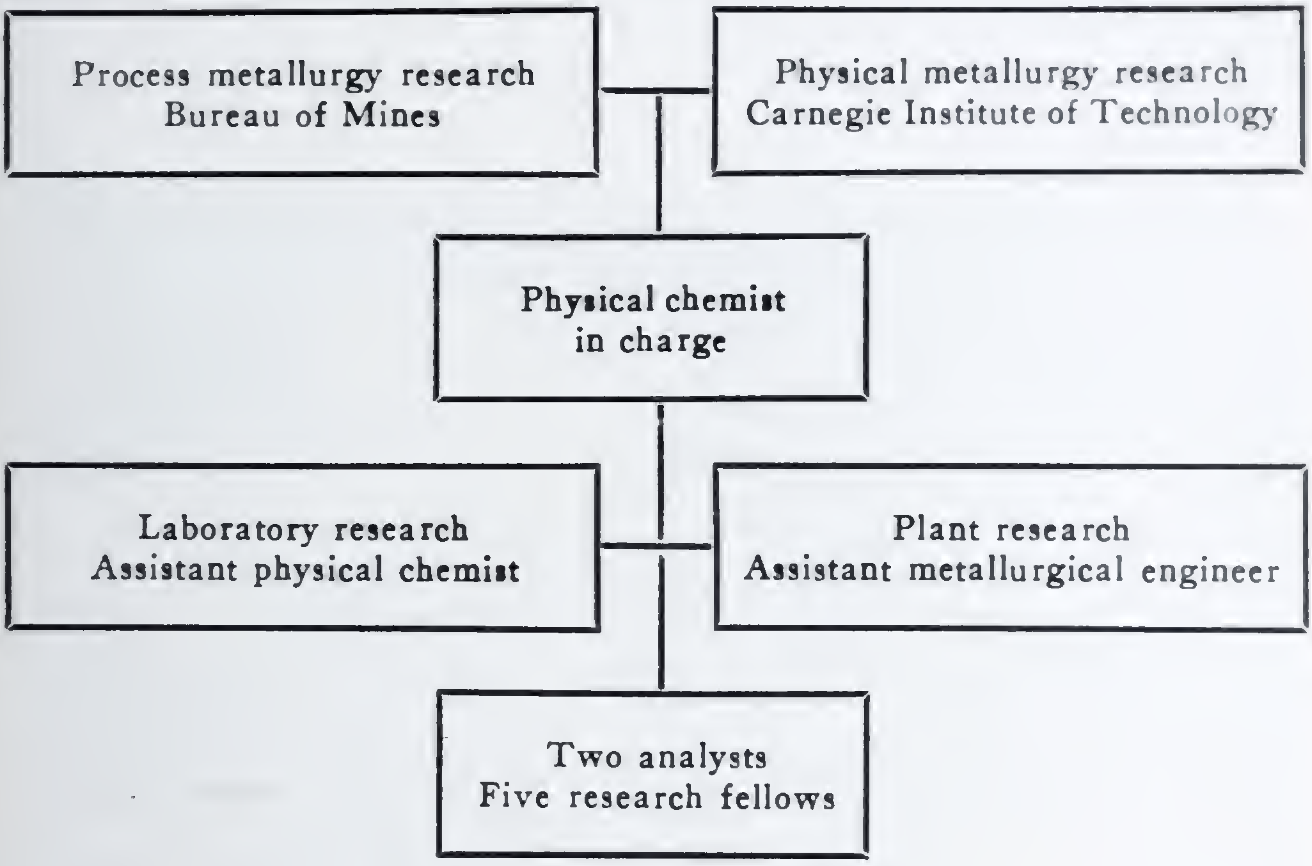

Fig. 1. Organization Chart.

freely given so that it became possible to embark on the full program at once.

LABORATORY FACILITIES FOR RESEARCH

Electric-Furnace Laboratory. An essential part of the laboratory facilities for this co-operative research is the Electric-Furnace Laboratory (See Fig. 2-4) of the Bureau which was planned for great flexibility in use. Although essentially an electric-furnace laboratory, it is well equipped for fundamental work in many branches of ferrous metallurgy. Because of the comparative ease with which conditions within it may be controlled, the electric furnace is peculiarly suitable for use in studying characteristic reactions.

Power is received from the Duquesne Light Company at 4000 volts, three phase, and is stepped down through 200-kilovolt-ampere transformers connected in open delta. On the primary side of the transformers are two 60-kilovolt-ampere induction regulators, by means of which the primary voltage can be boosted to 5600 volts or reduced to 3200 volts. The secondary winding of the transformers is divided into four parallel circuits with eight leads to the switchboard.

By means of tap-changing switches these circuits may be connected in multiple, series multiple, or series, giving three normal voltages of 50, 100, and 200 volts, respectively. The induction regulators give the intermediate steps, and voltages from 30 to 280 volts may be obtained in a limitless number of steps. For small work where a lower voltage is desired, current of 13½ kilovolt-amperes at from 5 to 50 volts is

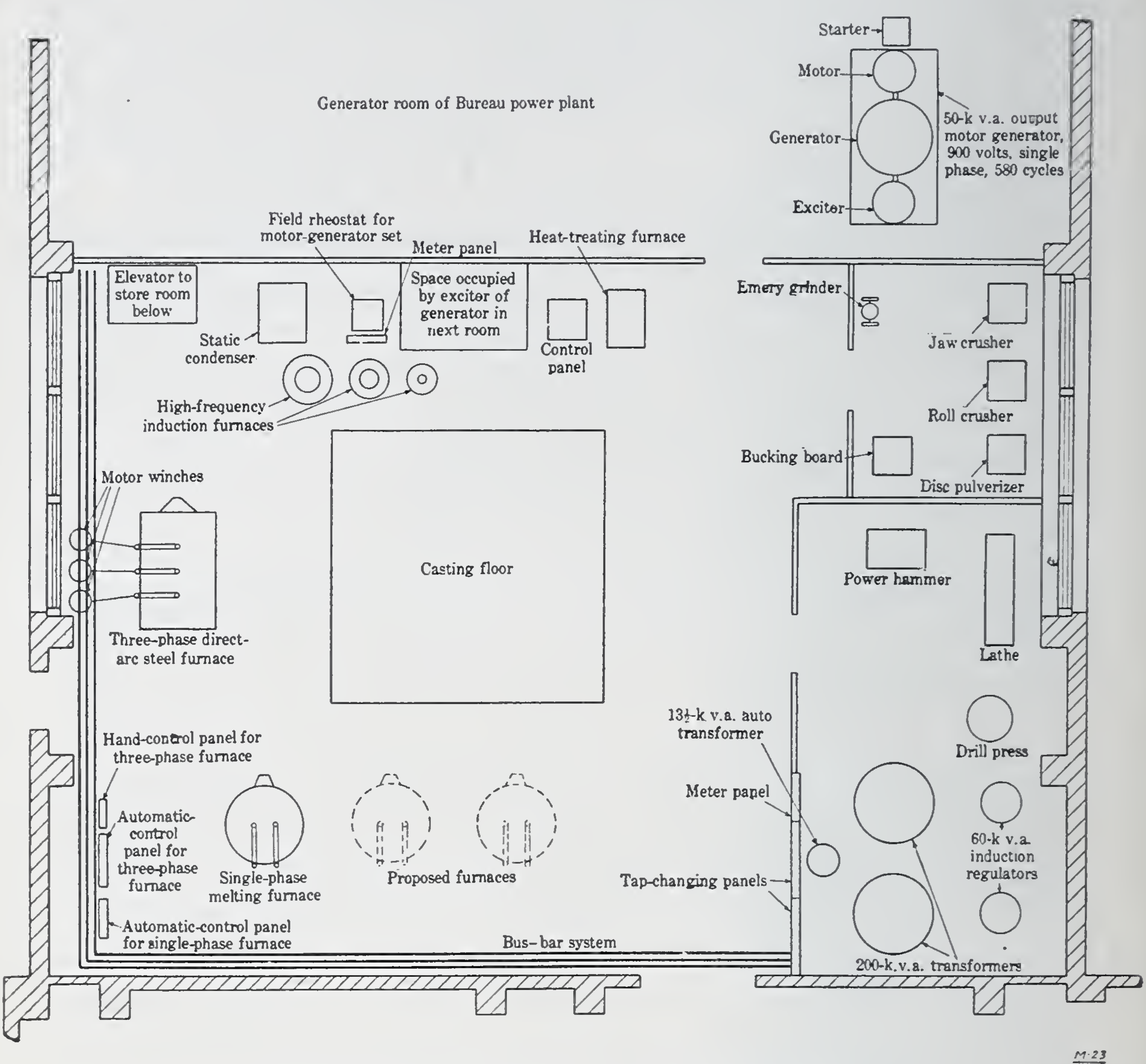

Fig. 2. Plan of Electric-Furnace Laboratory.

supplied by an auto-transformer connected on the secondary side of one of the large transformers.

An oil circuit-breaker equipped with definite time relays and undervoltage device protects the system from overloads. Meters for measuring watt-hours, and indicating kilowatts and secondary volts and amperes are mounted on the switchboard. Two single-phase

operations can be carried on simultaneously with independent voltage control and independent meter readings, or one three-phase operation can be carried on at a maximum of 350 kilovolt-amperes with the meter indicating three-phase power readings. This great flexibility

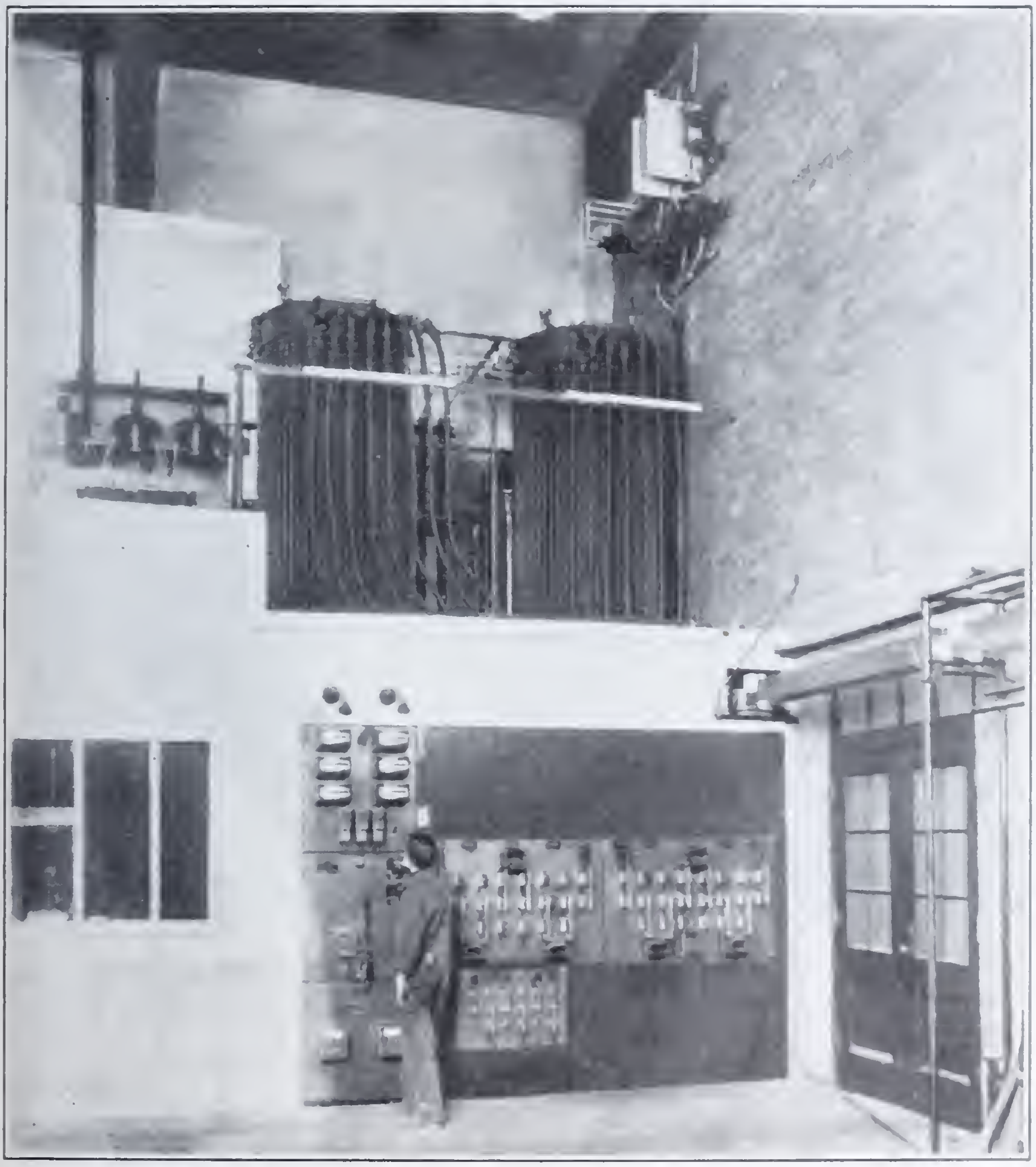

Fig. 3. Main Switchboard and Transformers in Electric-Furnace Laboratory at Pittsburgh Experiment Station.

permits the power requirements for almost any kind of an operation to be easily obtained.

Two direct arc furnaces are installed as permanent equipment. The smaller—a single-phase "'Lectromelt" built by the Pittsburgh Electric Furnace Corporation—has a holding capacity of about 250

pounds of steel. The larger—a three-phase furnace with three electrodes in a line—has a capacity of 1000 pounds of steel; it is "home made" and was originally designed for melting sponge iron. In both of these furnaces the control of the electrodes is automatic. Other furnaces, to melt refractory materials, for example, will be built as needed. Three copper bus-bars run along two sides of the laboratory at a height of eight feet from the floor and allow connections to be made at any point.

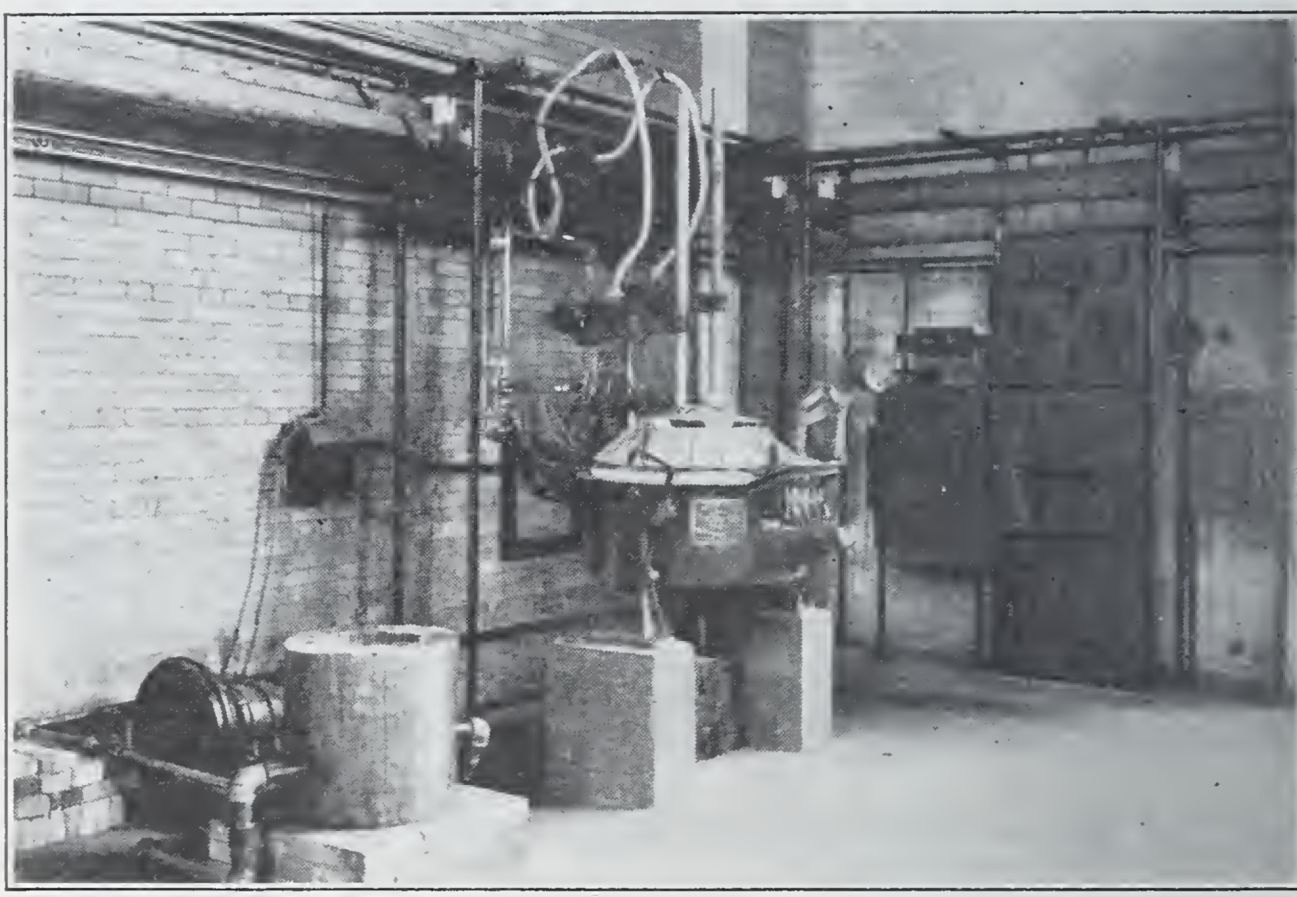

Fig. 4. Furnace of 250-Pound Capacity in Electric-Furnace Laboratory at Pittsburgh Experiment Station.

A motor-generator set, with an output of 50 kilowatts, supplies single-phase alternating current at 900 volts and 580 cycles to high-frequency ironless induction furnaces of the Ajax-Northrup type. That it may be away from the dust of the furnace room, the motor-generator set is situated in the adjoining room of the power-house. A battery of static condensers is so arranged that by means of knife-switches any desired number can be thrown in parallel with the furnace to correct the power-factor. The furnaces themselves, designed with the aid of E. F. Northrup, are of graduated sizes and will be remodeled from time to time to suit the peculiar conditions desired.

A heat-treating furnace with automatic temperature controller and recorder completes the furnace equipment. It is good for a sustained temperature of 1000 degrees C., or about 1800 degrees F.

The furnaces are arranged around the walls of the room, and the center is thus free for use as a casting floor which will be handy to all furnaces. The casting floor will be supplied with flasks and molding sand as well as ingot molds.

One end of the laboratory is partitioned off to form two rooms. One is a grinding and sampling room, which is equipped with a jaw crusher, set of rolls, disk pulverizer, bucking board, and coarse grinding-wheel which will be used largely for shaping refractory brick when odd shapes are needed. The other room is a combined tool and instrument room and shop. The shop is equipped with a drill-press, lathe, forge and anvil, and grinding-wheel. For breaking down steel billets there is a 50-pound, belt-driven air hammer.

Storage space is provided in the basement beneath the laboratory, with which an elevator provides communication. A ventilating system equipped with a Sturtevant blower will remove smoke and fumes from the laboratory.

Value of the Electric-Furnace Laboratory to the Pittsburgh District. The value of the Electric-Furnace Laboratory in the solution of problems of immediate practical interest to the industry was demonstrated during the very first year of its existence in a study of the physical properties of low-carbon, high-manganese steels. This research was conducted in co-operation with a group of three companies who were particularly interested in the properties of these steels when subjected to usage at high temperatures.

A number of these special steels were made in this laboratory, and physical tests on the resultant steels were made by the Institute. A preliminary report of this research was given last week at the annual meeting of the American Insitute of Mining and Metallurgical Engineers at New York, and will be published in its *Transactions* under the title, "Characteristics of Low-Carbon Manganese Steel," by V. N. Krivobok of the Carnegie Institute of Technology, B. M. Larsen of the United States Bureau of Mines, W. C. Masters of the Graham Bolt & Nut Company, and W. B. Skinkle of the National Tube Company.

Metallographic Laboratory. The Metallographic Laboratory is housed in the main building of the Experiment Station and occupies two rooms. One room is for the preparation of samples. It contains a rough and a fine grinding-wheel and a bench of four horizontal polishing wheels. The polishing wheels can be used for abrasives in powdered form or backed with cloth or paper. The other room contains the microscopic equipment, which consists of a Leitz micro-metallograph instrument with camera attachment. Pictures may be obtained up to 2000 diameters magnification. For visual examination there is a Bausch & Lomb binocular microscope. Camera equipment for low magnification is also available. A dark room that adjoins this laboratory is furnished with all accessories for developing plates and printing photomicrographs.

Other apparatus consists of a Brinell meter and a Shore scleroscope for testing hardness.

Chemical Laboratory. The Chemical Laboratory, adjacent to the Metallographic Laboratory, is equipped with standard apparatus

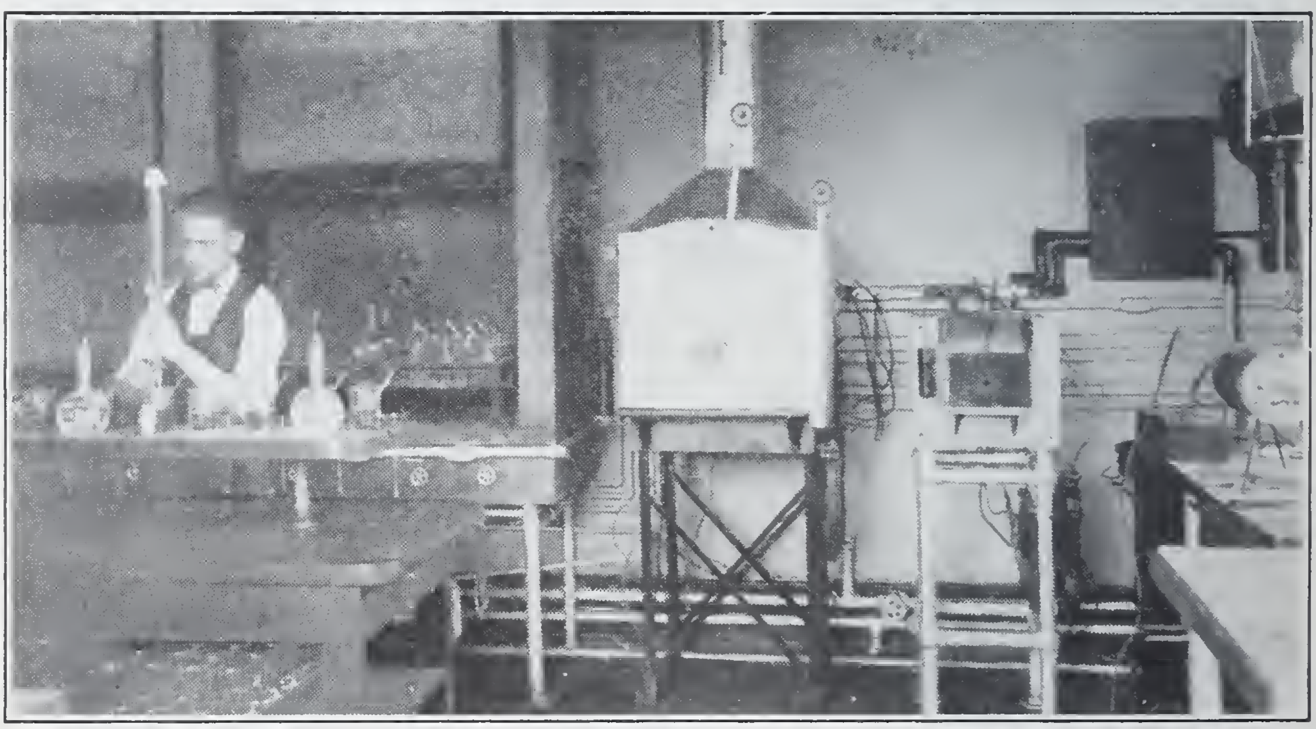

Fig. 5. Part of Chemical Laboratory for Metallurgical Work at Pittsburgh Experiment Station.

for making all necessary metallurgical and refractory analyses. (Part of the equipment is shown in Fig. 5.)

Laboratories at the Institute. The well equipped laboratories of the Department of Metallurgy and the Materials Testing Laboratory

of the Institute are available for the necessary physical tests, and valuable assistance will also be obtained from the Bureau of Metallurgical Research, which is an independent unit of the Institute conducting metallographic studies of the effect of heat treatment and of the phenomena of secondary recrystallization. The use of X-rays and spectrographic methods are special features of the methods of attack. (See Fig. 6-10.)

Fig. 6. Metallographic Laboratory at Carnegie Institute of Technology.

Fig. 7. Electrometallurgical Laboratory at Carnegie Institute of Technology.

Fig. 8. Ore-Dressing and Coal-Washing Laboratory at Carnegie Institute of Technology.

Fig. 9. Materials-Testing Laboratory at Carnegie Institute of Technology.

Fig. 10. Laboratory of Bureau of Metallurgical Research at Carnegie Institute of Technology.

WHY STUDY THE NON-METALLIC SOLID INCLUSIONS IN STEEL?

It may be asked why we have undertaken this elaborate five-year program on non-metallic inclusions in steel. Before answering this question permit me to define these inclusions. Non-metallic inclusions, or "sonims" as they are specifically called, are minute particles of slag, oxids, sulphids, or other non-metallic solid matter frozen in the metal. Their size varies from sub-microscopic colloidal particles to aggregates visible to the naked eye. Many of the unexplained failures of steel in use and abnormalities encountered in the manufactured product are attributed to the presence of non-metallic inclusions. It is necessary, therefore, in improving the quality of steel and in avoiding losses due to rejected product, to reduce the total amount of inclusions below certain limits. No definite figures can yet be given because our knowledge of the effect of non-metallics on the properties of steel is inadequate. The effect no doubt varies with the size, distribution, and nature of the inclusions.

The sources of non-metallic inclusions in open-hearth practice are:*

1. Non-metallic matter in or on the scrap charged.
2. Non-metallic matter in the pig-iron.
3. Non-metallics formed when the pig-iron is introduced into the open hearth by the oxidation of silicon, manganese, phosphorus, and aluminum; and by the introduction of sulphur from the iron.

*Herty, Charles H., Jr., Fundamental Research in Steel Manufacture: from abstract of paper read before winter sectional meeting of the American Society for Steel Treating, Washington, Jan. 20-21, 1927 (not yet published).

4. Formation of non-metallic matter when the heat is worked with ore or pig-iron.

5. Formation of non-metallics when the final additions are made.

The amount of non-metallics in the finished steel from any of these five sources depends upon the nature of the slag—chemically and physically—and the rate of elimination of sonims, which is, in turn, controlled by the nature of both inclusion and slag; by the viscosity of the steel; and by the agitation of the bath, and the temperature of the bath.

Objectives of Research on Non-Metallic Inclusions. The practical objectives of research on inclusions are (1) to provide enough fundamental information on the influence of the amount and type of inclusion on the properties of the steel so that specifications for the inclusions can be written just as is now done for sulphur, carbon, and phosphorus; and (2) to understand the mode of formation of inclusions of various types, and to determine their rate of elimination under various conditions so that the quantity and type in the final steel can be brought within the desired limits.

Importance of Physical Chemistry. Sir Robert Hadfield, the famous British metallurgist, has said:*

"Physical chemistry is the fundamental science of steel making. The basic reactions of steel manufacture depend upon some chemical reaction of oxidation, reduction, or some reversible displacement in a somewhat viscous liquid phase, and the resulting changes are largely influenced by temperature conditions; that is to say they fall into a class of chemical changes governed by thermodynamical laws. . . . The deoxidation values of Brinell for carbon, silicon, and manganese, are an instance of data, obtained by direct experimental methods, which at the present time are being confirmed by the modern methods of the study of chemical equilibria. . . . As regards the formation of inclusions, physical factors such as the viscosity or the fluidity of the steel and slag and surface tension effects are of undoubted importance."

Method of Attack on the Sonims Problem. We are in thorough agreement with Sir Robert and are applying physico-chemical methods to both laboratory and plant research.

*Hadfield, Robert, Physical Chemistry in Steel-Making. Transactions of the Faraday Society, 1925, v. 21, p. 172-175.

In order to determine and control the rate of elimination of non-metallic inclusions a number of fundamental studies are required. These (again according to Hadfield) fall into two classes:

1. Studies which will enable us to understand more about the formation of non-metallics.

2. Studies which will reveal the exact mechanism and conditions affecting the rate of elimination.

Some of the studies under the first head are (*a*) equilibrium between slag and metal; (*b*) equilibrium in the metal phase; (*c*) relative rates of deoxidation of various deoxidizers; (*d*) equilibrium conditions between various deoxidation products; (*e*) rate of diffusion of FeO from slag to metal; and (*f*) surface-tension and viscosity relations between the deoxidation products.

The fundamental studies under the second head of rate of elimination are (*a*) agglomeration of inclusions; (*b*) surface-tension and viscosity relations in slags; (*c*) viscosity of steel; (*d*) rate of upward settling of inclusions; and (*e*) rate of absorption of inclusions by slags. These fundamental studies involve a tremendous amount of work and can not be completed in a short time by a few investigators. However, these studies are necessary before non-metallic inclusions may be put on the same basis, in so far as our knowledge of them is concerned, as the other elements in steel.

PROBLEMS NOW IN PROGRESS UNDER THE CO-OPERATIVE RESEARCH

Action of Ferrous Oxid in Iron. As the basis of almost all of the non-metallic inclusions in steel is FeO, it was necessary to extend our knowledge of the action of this compound in iron as far as possible at the beginning of the co-operative research program. For this reason two of the research fellows were at once put on problems dealing with the properties of FeO in steel and slag—namely, section II A, 1-4, of the program already given. The first problem covers the determination of the solubility of FeO in iron under a slag of 100 per cent. FeO, and the effect of temperature on the solubility. The second problem is the determination of the distribution ratio of FeO between slag and metal for simple synthetic slags, beginning with the system FeO-CaO over pure iron, next FeO-SiO_2 over pure iron, and then FeO-CaO-SiO_2 over pure iron, etc. In both problems the melts are made in a Northrup high-frequency induction furnace,

with a crucible made of fine, fused magnesia oxid. The melt is cast in thin wedge-shaped ingots in order that they may solidify quickly and prevent any change in the amount of FeO dissolved in the iron during cooling. Samples are then taken at various points in the ingot for determination of oxygen by the Ledebur method. Sections are made for microscopic examination and the slag is analyzed for determining the distribution ratio of FeO between slag and metal.

Formation and Identification of Inclusions. The ingots and samples from these two problems also serve as part of the working material for the third research fellowship problem—II B—also started last August, on the subject of the formation and identification of inclusions. Other melts are made in the arc furnace in which the heats are "killed" by the addition of various deoxidizers such as manganese, silicon, and aluminum. The inclusions formed are studied from the viewpoint of "type of inclusion," "size of inclusion," and "effect of inclusion on physical properties of steel." A study of methods of identification is an essential part of this problem, as is the study of inclusions in the samples taken in the plant research problem to be described later.

Viscosity of Open-Hearth Slags. The fourth fellowship problem—section IV A—on the determination of the viscosity of open-hearth slags was taken up at the outset of the program because of the many difficulties involved in developing the viscosity apparatus, and the large amount of work necessary to determine the viscosity relations of open-hearth slags. It is not expected that much more than the development of the apparatus can be done during the first year's program. A torsion-type viscosimeter, similar to that used by Feild and Royster* in their work on blast-furnace slags, has been constructed. The experimental difficulties with open-hearth slags are much greater than with blast-furnace slags because the high iron content of the former requires the maintenance of a neutral atmosphere.

Abnormalities in Case-Carburized Steel. The fifth fellowship problem in progress this year, on a study of the cause of abnormalities in case-carburized steel, is a continuation of the same problem on

*Feild, A. L., and Royster, P. H., Slag Viscosity Tests for Blast-Furnace Work, 1918. U. S. Bureau of Mines, Technical Paper 187.

which a previous fellow worked last year. Results obtained thus far this year indicate that this problem is also connected with the effect of non-metallic inclusions, and that, as our knowledge of inclusions and their effects increases, we may be able to avoid the cause of abnormal steels.

IMPORTANCE OF CLOSE CONTACT OF LABORATORY AND PLANT RESEARCH

A recognized principle of the plan of the co-operative ferrous metallurgical research which I have described is that there should be close contact between the plants and the laboratory. This has been made possible through the active interest of the Advisory Board, and the fact that the three principal members of the research staff have each had several years of practical experience in steel plants, as well as thorough scientific training. The metallurgical engineer of the staff spends his entire time on research problems conducted on an operating scale in steel plants, with the aid of the plant staff and other members of the Bureau's staff when required. At the present time the plant problem—section III B—on the "Elimination of Inclusions in the Open-Hearth Furnace" is being conducted at the Homestead works of the Carnegie Steel Company.

Measuring Oxygen Content of Steel. The first test of importance was run to determine the feasibility of measuring the oxygen content of steel samples by "killing" the steel with aluminum in the mold and analyzing for Al_2O_3 by means of dissolving the steel in cold dilute nitric acid and examining the residue. This test showed that aluminum was oxidized by the air and that this procedure could not be used. In all subsequent tests the steel was poured "wild" in a special-shaped mold. The second and third tests were run to determine the effects of additions of ferro-silicon in the furnace on (1) the oxygen content of the steel; (2) the type of silicates formed; (3) the elimination of these silicates; and (4) the elimination of other non-metallic matter which might be in the steel before the addition of ferro-silicon. All samples are being analyzed for non-metallic inclusions and the results for corresponding heats will be compared. Slag-viscosity determinations were made and samples of the slags are being analyzed. Sections of the metal are being examined and excellent photomicrographs showing the inclusions have been made.

The results thus far obtained in the plant investigation problem have greatly aided in conducting the purely laboratory investigations on identification and controlled formation of inclusions in the electric furnace. At the same time, information of value is being obtained for the steel manufacturer in the early stages of our research program without waiting for the completion of the more fundamental laboratory research problems.

RESULTS OF CO-OPERATIVE RESEARCH

Six months have now elapsed since the five-year research program on the study of non-metallic inclusions in steel was started. Of course it is too early to report definite results, but I can state that the project has been successfully launched and the results of experimentation thus far obtained have shown that the program is well conceived and is bound to produce the fundamental information needed by steel makers to improve the quality of steel. This type of research does not redound to the advantage of a few manufacturers, but is of direct value to the entire steel industry as well as to the users of their product. It is needless to say that reports will be published promptly on the completion of each phase of the work.

DISCUSSION

C. M. Johnson, *Chairman*:* You have heard an inspiring paper, which ought to make you very enthusiastic and hopeful of great results. There may more come of these investigations than merely finding out all about the causes and prevention of inclusions. The results may have some bearing on the problem of rust prevention. The retiring Chairman's address should provoke a lively discussion. Dr. Herty is here, also, to answer any questions, and you thus have a splendid opportunity to inform yourselves as to what is being done and to make helpful suggestions.

James Aston:† I feel at a disadvantage in this discussion. All who know Mr. Fieldner will agree that after he gets through with a subject it has been considered so completely and logically that there is little left to discuss. All that I may do is to reflect the point of view of one of the co-operating bodies; that is, the body which is linked

*Director, Research and Metallurgical Departments, Park Works, Crucible Steel Co. of America, Pittsburgh.

†Head of the Department of Metallurgy and Mining, Carnegie Institute of Technology, Pittsburgh.

up with the educational phase of the problem. This work is a partnership, because co-operation is a partnership, and in a partnership we give and we receive. The Carnegie Institute of Technology is financing two fellowships each in mining and metallurgy. We also contribute the instruction which is correlated with the fellowships. This is a vital feature, because one of the fundamental reasons for these fellows taking up the work is that they are getting advanced education. We are furnishing the secretarial part of the work, connected with the Advisory Board relationship. Last, but not least, we are giving our equipment facilities to the extent that they dovetail in with the investigations in progress; also our services as far as they may assist in the co-operative effort.

Now, what do we receive? I am not putting this into a secondary position, because I feel that the Carnegie Institute of Technology is getting an ample return. There are three real functions of an educational institution. First and primary is the matter of education. The second function is that of instruction of graduate order for those who may wish to go farther in the professional line than they may be able to go in the ordinary college course. The third function is that of research. Considering graduate instruction, there are five fellows in metallurgy and eight in mining; nine of the 13 being supported by industry or by the Advisory Boards.

That, however, is only a minor part of it. I believe very fully and firmly that, as a result of this co-operative relationship, we have secured a more mature and generally all-around better class of workers than would be possible if the sole attraction were the compensation attached to the fellowship.

The research work of an institution such as the Carnegie Institute of Technology may be in two lines. One is the pure science side and the other is that of more applied science. We have in our Bureau of Metallurgical Research a personnel which is tackling some of the very abstract fundamental problems related to the science of metallurgy. That research work which is directed through the Advisory Board will logically take the more applied problems of the industry. In many ways this phase is more difficult in college laboratories and in selection of fellows and in intelligent direction of their researches. I personally feel very strongly that there is a tremendous field, and it is a real function of a technical institution to foster and to conduct fundamental research even if it is of a very abstract type; neverthe-

less, if that research can still be fundamental and can be dovetailed in with the need of industry, it is much more important because it is more immediately useful and of greater economic value. While it is a more difficult phase to administer, I believe it is being done admirably under the existing arrangement. Each fellow is a cog in a co-ordinated machine, and his efforts are immediately productive with a minimum of lost motion and misguided effort.

As for its effect on the work of our undergraduates, that is not quite so definite. I feel, however, that any institution which gives graduate instruction, and has at the same time well organized and important research activities, reaps a benefit in the undergraduate field. There are several intangible benefits which result from this association. Our institution profits by the contact with, and the influence of, Advisory Boards made up of men of prominence in industry. Research and publication of value in the joint relationship are bound to attract attention to the fountain head, and the Carnegie Institute of Technology as one part of the triple relationship should profit in adequate measure.

A. L. FEILD:* I am pleased to see launched under such auspicious circumstances a systematic investigation of non-metallic inclusions in steel. It is inevitable that before its completion this work will, in greater or less degree, touch upon practically every phase of steel manufacture, in view of the fact that non-metallic inclusions occur in the raw materials; are never completely eliminated during the melting, refining, and finishing operations; and, in fact, may increase markedly during certain periods of the manufacturing process. A five-year estimate for the time required to carry through such a program is an optimistic one.

Mr. Fieldner says that it is necessary, in improving the quality of steel and in avoiding losses due to rejected product, to reduce the total amount of inclusions below certain limits. I am glad to note that he does not suggest the desirablity of eliminating inclusions completely; it is certain that this will never be accomplished. Furthermore, I believe it will be generally admitted that the maximum limits for the various inclusions which enlightened practice will ultimately set will vary very greatly with the composition and thermal treatment of the steel and the use to which it will be put. In an ingot iron, for

*Metallurgist, Canton, Ohio.

instance, the sum of the "big five"—carbon, manganese, sulphur, phosphorus and silicon—may not exceed 0.15 per cent., and yet, as a rule, the total oxygen in such a product will lie between 0.025 and 0.05 per cent., corresponding to from 0.087 to 0.17 per cent. of the non-metallic impurity FeO. The high content of iron which such an ingot iron shows upon analysis is obviously due to the fact that the major impurity, FeO, itself contains 78 per cent. iron. The presence of a relatively high non-metallic content in ingot iron, however, has not contributed appreciably to increased rejections in rolling or other mechanical operations, nor has it attracted particular notice in connection with the uses to which ingot iron is put. On the contrary, in the case of certain types of alloy steel designated for heat treatment and severe service conditions, a product which, in the ladle before solidification, contains a total oxygen content of 0.0035 per cent. (or from 1/7 to 1/14 of that of ingot iron) may be subject to an appreciable percentage rejection on final inspection of the finished part; or, it may show no rejections whatever, depending upon the particular type of pouring, mold, and rolling practice followed. In other words, difficulties due to non-metallics in quality steels may be caused by segregation of non-metallics during solidification rather than by the presence of any objectionable amount of suspended non-metallics in the ladle metal. In this connection reference should be made to the investigations of Dickenson, recorded in his paper, "A Note on the Distribution of Silicates in Steel Ingots."*

In view of the complications in the problem arising from segregation of non-metallics in the ingot, it would be exceedingly difficult, if not impossible, to draw up specifications to govern the permissible amount of non-metallic inclusions along any lines similar to those which now govern the ordinary elements in steel. The difficulty here has to do in the main with the question of obtaining a representative sample or samples from the ingot or finished bar or sheet. Troubles in fabricating and in service would arise generally in that portion of the article where the percentage of non-metallic inclusions was unduly high because of segregation. If it were possible to determine the maximum concentration of non-metallics in the ingot, this alone would not be sufficient, for the reason that the extent of segregation, as well as its intensity, would enter into the problem. When to such difficulties arising from segregation is added the difficulty of establishing a

*Journal of the Iron and Steel Institute, 1926, v. 113, p. 177-196.

more or less arbitrary standard for each grade of steel and type of service, the complexity of the subject is apparent.

This complexity, however, should not act as a deterrent to systematic research, but rather should stimulate research investigators to exert their utmost efforts to arrive at the fundamentals and thus simplify the problem. It is certain that the complexity presented by the problem resides chiefly in our failure properly to understand it as a whole. That part of the subject which we do not understand is without doubt made more unintelligible by the prevalence of a tremendous accumulation of erroneous observations and incorrect theories, which would seem to perpetuate themselves in proportion to their degree of error or of incorrectness. The conscientious reader of metallurgical literature who has a deficient background of personal experience must surely suffer from a species of technical indigestion, if not nausea. It is pre-eminently a day of specialization even within the confines of ferrous metallurgy. The specialist does not always stay within his own specialty, but digresses into other adjacent fields where his slightest suggestion is apt to receive much more attention than it justly deserves. There is a real need to-day for the development of a new type of metallurgist who is trained and experienced in steel making, in the properties and structure of the finished product, and in the engineering principles which govern the use to which the product is finally put. Results of research are already accumulating more rapidly than they are being assimilated or applied.

It is easy to maintain that non-metallic inclusions lead to fatigue failure, for instance. Several years ago quite a furor developed on this particular phase of ferrous metallurgy. It is still generally believed, I presume, that in some way non-metallic inclusions and failure by fatigue are inseparably connected. Nothing could be further from the truth. If we can imagine a piece of steel entirely free from inclusions, it would inevitably fail by fatigue, provided the stress and number of reversals were sufficiently high. A fatigue failure does not necessarily start at a non-metallic. The important question at issue here is whether the elimination of inclusions beyond the point now accomplished in good practice will result in any appreciable increase in endurance limit. All indications point to the fact that endurance limit is, as a rule, directly proportional to ultimate strength, nor does the presence of a large number of manganese sulphid non-metallic inclusions affect the endurance limit to an appreciably greater

degree than it affects the ultimate strength. Certainly the current theory here needs revision.

In conclusion, I would urge upon the co-operating agencies involved in the program outlined by Mr. Fieldner and Mr. Herty the advisability of refraining from attaching to non-metallic inclusions any larger measure of opprobium than they deserve. Already there is a danger that the steel consumer has been supplied with a verbal symbol of that which is undesirable in his product before he or his metallurgist has assimilated the fundamental bases governing the occurrence of non-metallic inclusions in steel and their true effect upon the product. After all, steel is valued and used chiefly because of its physical and mechanical properties in the shape and condition in which it is used in service, and on account of its behavior during service. These are the ultimate criteria beyond which no commercial test should be devised and adopted.

CHARLES H. HERTY, JR.:* As far as concrete achievements are concerned, we have some very interesting results from the fundamental problems and in the practical application of some of them; but I think it is a little too early to talk results until we get enough to co-ordinate them.

The work is going very well. We have a 250-pound Moore "'Lectromelt" furnace and two Ajax-Northrup high-frequency induction furnaces in which we make the experimental melts. The two induction furnaces have a capacity of about 100 pounds each, and we have a smaller induction furnace which will be installed soon. This furnace will enable us to make melts of from 1 to 10 pounds, and will enable us to speed up certain phases of the investigation.

Rather than speak of concrete results, I should like to discuss one point brought out by Mr. Feild. One of the main points we are keeping in mind is that we must first know how non-metallics, both in amount and type, affect the properties of steel, and, therefore, how far it is economically necessary to go in eliminating non-metallics. Mr. Feild pointed out the fact that it is a very complicated subject, and there are lots of different kinds of non-metallics and many different kinds of service for steel. We do know that there are certain cases in steel—and probably more than some of us realize—where the non-metallic content does affect the rolling and properties of the fin-

*Physical Chemist, Pittsburgh Experiment Station, U. S. Bureau of Mines.

ished steel. One of the problems we are working on first is to get down to the finished steel and see just how the "dirt" affects the properties of the steel. In addition to that, we have another very interesting piece of work. Instead of starting with the finished condition of the open hearth we are going right back to the blast-furnace—starting in with the ore, the coke, and the stone charged into the blast-furnace and following it right on down to the finishing processes. The two are running along side by side and will supplement each other very well.

As far as the investigation at the United States Bureau of Mines is concerned, I think that this investigation will result in much more than a knowledge of straight non-metallics. Corrosion of steel was mentioned, and we hope to get into that because we have everything you ever saw from very low non-metallic to "dirty" steel—the dirtiest steel you ever saw.

The second point is that in working out some of these fundamental things we are going right down to the heart of what makes the open-hearth furnace make open-hearth steel. Studies on slag viscosity, solubility relationships, etc., are applicable to every open-hearth furnace and apply to the question of rapid working just as much as they apply to non-metallics. We know that the fundamental problems are going to lead to a great many fields other than non-metallic. Of course we keep our eyes on the non-metallics, but we necessarily include other problems.

In most of the problems we are using pure iron, electrolytic, or "Armco" iron, and we have to use crucibles which are impervious to slag. Our greatest success has been attained through the use of fused magnesia, crushed to pass a 100-mesh screen, mixed with one to one hydrochloric acid to a thick paste and then rammed into a mold and burned at a high temperature.

In determining the non-metallic content of steel we are using a method brought out last spring. Briefly the method is to dissolve a large sample (100-300 grams) of the steel in cold nitric acid, and by suitable treatment of the residue to obtain certain of the non-metallics in the steel.

Up to this time we have been working on the inclusions containing silica or alumina, and we have obtained some very interesting data, both in our small furnaces and in commercial open hearths. Some of the information obtained has absolutely changed my ideas about condi-

tions in the open hearth. We have obtained data on one subject which will be interesting to everyone. You are all familiar with the elimination curves of carbon, manganese, etc. There have been hundreds of those curves determined. We have curves on silicate elimination which are very remarkable, and which show how slowly the silicates are eliminated at certain times and how rapidly at other times. I think that by the end of the present year we shall have new material in elimination in the open-hearth furnace, and in the fundamental reactions that take place there, which will help us in determining just what kind of materials are best to put in the furnace.

I would like to say that the co-operation of the Advisory Board has been 100 per cent.; all the plants we have gone into have been entirely open to us, and those in charge have given us the finest kind of help.

C. M. Johnson, *Chairman*: I should like to ask whether you are going to continue to make all of your melts in basic-lined furnaces or if you will use acid linings, also. We all know the unsettled question as to the comparative merits of basic and acid steels. Many still think acid steel is the best and insist on getting it. It is to be hoped that in the course of this five-year program many melts will be made with acid linings, and that the facts developed will settle once for all which kind of steel is the better.

Crucible steel is made in a container which is 50 per cent. reducing material (graphite) and 50 per cent. acid material (bond clay and sand), with access of air entirely prevented. It would seem to me that the committee would want to use this steel as a standard to test all of its methods. While the volume of crucible steel produced to-day is smaller than formerly, yet it must be the cleanest and freest from oxids of all steels. It should be tested in conjunction with your acid and basic steels to get comparative data as to quantity and nature of its inclusions; tensile, torsional, and fatigue properties; and the exact degree of its superiority over the less expensive steels.

Every day hundreds of dollars are spent on tools and dies that weigh but a few pounds each. I am told that one great concern in this district, which uses much steel, has laid before the steel manufacturers a specification requiring that one of their important grades of carbon steel must be melted in a crucible, and that the major portion of the charge shall be of charcoal iron.

Charles H. Herty, Jr.: We have to use an acid lining when we work on silica slag. We could not use basic linings on that.

H. E. Slocum:* The subject of sonims as presented by Mr. Fieldner should be of great interest to everyone concerned in the manufacture of steel.

One of the great problems of the steel industry is to produce a product free from non-metallic or oxidized impurities which are formed either during the refining period, or result from the addition of recarburizers.

The use of deoxidizers as a means of removing dissolved oxids or occluded oxygen has been given much consideration in the past, but very little attention has been paid to the formation of slags during the refining period which will prevent to a large extent an overoxidized bath and the subsequent formation of sonims resulting from the addition of alloys. One of the principal factors is to have present during the refining period a slag with a low iron content, to avoid as much as possible the presence of dissolved oxids in the bath during the recarburizing period.

The percentage of manganese in the slag at this time is another important factor. Manganese exerts its influence according to its concentration in the slag and metal.

It has been found in practice that the bath loses manganese when the percentage of MnO in the slag is less than that of the FeO; that it gains manganese when the MnO is greater than the FeO; and that it neither loses nor gains manganese when the MnO and FeO are equal. This seems to be independent of the total percentage of iron or manganese in the slag, but concerns only their proportions relative to each other.

Some time ago 32 experimental heats were made by a well known steel company. The results indicate that after the slag contains as much manganese as iron, the bath ceases losing manganese even in an oxidizing atmosphere. Further oxidation of manganese can proceed only as the slag receives iron oxid from oxidation of the bath or as iron oxid is added from an outside source. The conclusions drawn are that a slag containing less manganese than iron not only oxidizes manganese from the bath, but is usually coexistent with a bath containing dissolved ferrous oxid; and that the presence of manganese

*Chief Chemist, Jones & Laughlin Steel Corporation, Pittsburgh.

equal to iron in the slag prevents to a large extent the presence of ferrous oxid in the bath, or even tends to remove it. However, under certain conditions, dissolved oxids can exist even in the presence of manganese.

It seems to be the general open-hearth practice to have a bath during the refining period containing a percentage of from 0.06 to 0.15 per cent. residual manganese, varying according to the carbon content. Bath tests taken at this time show varying amounts of oxygen, thus proving that it is possible to have dissolved oxids even in the presence of manganese. Traces of manganese are also found in the Bessemer process, together with dissolved oxids. At the drop of the carbon flame, when the temperature is approximately 3000 degrees F., and the bath is overoxidized, 0.02 to 0.04 per cent. manganese is still present.

Slag tests taken during the refining period at the open hearth show that, in most cases, the FeO exceeds the MnO. Under this condition it would be expected that the bath would lose manganese, but this is not the case when the residual manganese is low. Dissolved oxids can exist in the presence of the low residual manganese, and it is these dissolved oxids that we expect to eliminate with proper slag formations. This can be accomplished to a great extent, especially in the tilting-type furnaces, by pouring off a portion of the slag containing the oxidized impurities and forming a new slag with a higher percentage of MnO than FeO. The bath thus, to a large extent, loses its dissolved oxids by virtue of this increase of manganese. In producing certain grades of steel, when bath tests show a manganese content of 0.25 or over, due to the residual manganese plus that reduced from the slag, only traces of oxygen are found, thus eliminating, to a great extent, the chances of forming sonims during the recarburizing period.

In acid open-hearth practice, under normal conditions, the silicon which is reduced from the silica in slag during the refining period is the chief factor in oxygen removal.

Although, as stated by Dr. Herty in a recent paper, the MnO in solution in some cases may cause imperfections in the finished product, we believe that a much more uniform grade of steel can be made by the use of high manganese in the initial charge, followed by the addition of manganiferous ore at certain stages of the process, thus helping to form the proper slag condition with the subsequent avoid-

ance of overoxidation and formation of sonims during the recarburizing period; and further, to prevent chemical reactions taking place during teeming and solidification.

We look forward to the time when Dr. Herty publishes his final paper, as he probably will present some interesting facts pertaining to slag formations which will be of great value in aiding the production of steel with a minimum amount of sonims. However, Dr. Herty will probably find that chemical combinations of slag formations are somewhat like radio bridge hands—one seldom gets two alike.

J. O. Handy:* Mr. Fieldner has, I think, made it very apparent that the groundwork for co-operative research in steel metallurgy has been very well laid, and it is a safe prophecy that results of great importance to the industry will come from the work which was started six months ago. A considerable number of steel manufacturers have been interested in the development from the start, and many others, when the fundamental and thorough nature of the work was explained to them, have gladly given their co-operation.

There is no reason why, with the enthusiastic and competent research men who are working with the metallurgists in the steel industry, the great problem which still remains in the manufacture of steel—the exclusion of solid non-metallic impurities from steel—should not be carried to a conclusion. These impurities come from so many sources, and are of such various compositions and physical characteristics, that a great deal of detailed experimentation and study is required.

Dr. Herty has the problem well laid out, and if we of the Metallurgical Advisory Board and the affiliated representatives of manufacturers take our part in making available all needed assistance and facilities for carrying on the work, we should be extremely proud, and the industry at large will greatly profit from the results of the work.

It takes courage to begin with fundamentals. Manufacturers are apt to be impatient, although this is less true than was formerly the case. It is only, however, by beginning with fundamentals that we can place our knowledge of the solid non-metallic impurities in steel, and their influence upon the steel, as well as the methods of

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excluding or eliminating them, upon a basis comparable with our knowledge of other elements which influence the quality of steel.

It should again be emphasized that the whole steel industry will be benefited by what this fundamental research brings out, and while we have at present the support chiefly of the steel manufacturers of western Pennsylvania, northern West Virginia, and eastern Ohio, we expect to deserve a much wider support and interest.

T. D. LYNCH:* This problem is one in which I have been vitally interested since its inception as presenting a broad, comprehensive, and fundamentally a Pittsburgh problem; namely, the physical characteristics of steel making. Mr. Fieldner has given us a very good summary of the organization and the plan of attacking this most important problem.

The first step in any successful research is to make a complete study of the problem, what has already been done, and what needs to be done, and then plan the research to be conducted. This has been very well covered in Mr. Fieldner's address and shows how completely and definitely the plans have been laid. I am interested in the problem from the point of view of the consumer, and as such feel very keenly an economic need for a more uniform and more reliable steel than is furnished in the large tonnage of steel used to-day. Great advances have been made, but this study of the fundamentals of steel making can but lead us to a more reliable steel, and more reliable structures.

The economical manufacture of high-grade steel is therefore one of the essential features so much needed in design when we are forced to use our structural materials so near their maximum strength. Economical design may well go hand in hand with greater uniformity of material.

I feel that this investigation will help to establish a more uniform material, and as a member of the Board representing Pittsburgh industry, I shall certainly endeavor to assist in reaching its successful conclusion.

E. H. MCCLELLAND:† It may interest certain members of the Society to know that the Carnegie Library of Pittsburgh has in prog-

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ress a bibliography of sonims and occluded gases in steel. The material so far assembled is available for use in manuscript form in the Technology Department. This Department is strong in the literature of ferrous metallurgy, and the material on impurities in steel, though widely scattered, is quite extensive. For more than a year Miss Lois McCombs of the Technology Department has been devoting spare moments to the compilation of this list, which now comprises more than five hundred references. Thus handled, only in time which can be spared from more urgent work, the compilation will necessarily require some time for completion. Eventually the list will be published, but, in the meantime, it is available for consultation.

SOME FEATURES OF AUSTRALIAN BLAST-FURNACE CONSTRUCTION AND PRACTICE*

By David Baker†

INTRODUCTION

The construction of the Iron and Steel Department of the Broken Hill Proprietary Company, Ltd., Melbourne, Victoria, began early in 1913. It was planned at that time to build a 350-ton blast-furnace on tide-water at Port Waratah, three miles from the city of Newcastle, New South Wales, a coal shipping port at the mouth of the Hunter River.

In addition to the furnace there were to be three basic open-hearth furnaces rated at 60 tons capacity, a 35-inch blooming mill, a 28-inch rail and structural mill, by-product coke-ovens, power-plant, and repair shops.

Formal opening of the works by the Governor General took place in June, 1915, although the manufacture of rails had been in progress for over a month at that time, and pig-iron for some three months.

At that time the demand for steel was so great in Australia—almost entirely shut off from its usual import supply by the activity of the German submarines—that it became imperative to extend the works at once. The equipment for the initial installation was obtained almost exclusively from the United States, but the problem in 1915 was to make the needed extensions from material manufactured in Australia. At that time the government of this remote dominion of the British Empire was pushing with all haste the strategic railway connecting the east and west coasts of the continent, recommended by Lord Kitchener during a visit to that country a few years earlier. It was necessary, therefore, to provide rails for this important enterprise, but a still more urgent need was material to build ships, so that the government might use its dockyards located at the principal seaports, for the purpose of replacing some of those vessels commandeered for war service and those merchant ships that were rapidly being sunk.

In order to meet this situation, the federal government of Australia appealed to the board of the Broken Hill Proprietary Com-

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†Consulting Engineer, Philadelphia.

pany for not only rails and structural shapes, but steel plates and sections for ship frames. It was also necessary to provide foundry pig-iron, steel castings, large forging ingots for engine-shafts, and munition rounds, as well as other shapes.

At this time the lead smelters of the Broken Hill Proprietary Company, Ltd., at Port Pirie were making nearly 400 tons a day of silver-lead bullion besides quite a tonnage of zinc, and great credit is due the directors for their enterprise in undertaking the manufacture of iron and steel when their business was the mining and smelting of non-ferrous ores.

The great inducement to make this departure was the large deposit of high-grade iron ore controlled by the Company and used for flux, and the large tonnage of steel being imported into the country, thus offering an opportunity to increase the earning power of the Company and to extend its life; but it also put the Company in position to be of great assistance to the Australian government during the war.

In order to meet the requirements of the federal government, the works management decided it was practicable to roll the shapes required for ship construction, and to produce, in the blooming-mill, ship plates five feet wide and 25 inches long and from 7/8 to 5/16 inch in thickness, as well as large castings and forging ingots.

To carry out this program it was necessary to build another blast-furnace, more open-hearth furnaces, a steel and iron foundry, and three small mills. No. 2 blast-furnace was built entirely of steel manufactured on the spot, with the exception of the turbo-blower and the boilers, which were obtained from England and delivered without an accident. Later, two more blast-furnaces and a rod mill were added, and wire-drawing and sheet-rolling subsidiary industries were installed.

In addition to the construction problems which had to be met at this time, those in connection with the operation of the plant were quite as interesting.

The almost complete cessation of importations stopped the supplies of Australian magnesite, English ferromanganese and fluorspar, and American silica brick. To supply these deficiencies, prospecting for magnesite and fluorspar was started at once and a very pure supply of the former was secured which, when calcined, mixed with iron ore, made into bricks and twice burned, produced a very satisfactory

magnesite brick. A fluorspar mine was opened and a local brick company was finally able to produce a satisfactory silica brick. Manganese ore was also located, but as no blast-furnace could be spared to make ferromanganese it was decided to erect a small furnace to supply this alloy.

To carry out the program made necessary by the government's demands and the exigencies of the situation, great pressure was exerted on the mechanical shops of the state and adjoining states, while work at the plant was pushed night and day with all hands available. Altogether, at the plant and in the field, there was a great patriotic urge to overcome all obstacles, with the result that the plant kept up and materially increased the quantity and variety of its products. It was in connection with the construction and operation of the blast-furnaces, however, that certain departures from the usual practice were adopted, which I wish particularly to describe.

The iron ore supply of the Company is obtained from Iron Knob, about 30 miles from the shores of Spencer's Gulf, South Australia, an ocean haul of nearly 1200 miles from Newcastle, the site of the works. This deposit consists of several massive hills of nearly pure red hematite with practically no gangue, the iron ore averaging over 64 per cent.

The manganese content of the ore varies from 0.5 to 10 per cent., so that in making basic pig-iron it was economical to carry as much manganese in the iron as good practice in the open-hearth furnaces would permit; that is, from 1.8 to 2 per cent. There is no sulphur in the ore and not over 0.5 per cent. in the coke. The best coking coal in the Newcastle district comes from the Bore Hole seam and contains between 33 and 34 per cent. volatile matter.

COKE HANDLING

The small coal (unwashed) produces a coke with 19-20 per cent. of ash. The coke produced has a strong cell structure, but is quite friable and breaks up very easily until about the size of two-inch, when it resists further reduction as effectively as the average English coke. This friable quality of the coke caused a great many "dirt troubles" in the first furnace, and it was found necessary to change entirely the method of handling the coke. The large quenching car, and the use of the large bin at the furnace were therefore given up and, instead, a coke wharf was erected at the ovens and the coke forked into

narrow-gage hopper cars, each car having the capacity of a furnace skip. Later, an inclined coke bench was substituted, where the coke slid over grizzly bars into a pocket and was drawn into the small hoppers.

These narrow-gage hoppers were hauled to the blast-furnace by a locomotive, and switched in onto the larry car track as required. They were then dumped directly into the furnace skip. This method of handling the coke transformed the furnace work, stopped "dirt troubles," and made it possible to increase the production of this furnace, with a 13-foot hearth, to over 3600 tons per week of basic pig-iron. It was thought advisable to force the production in this way, due to the great demand for pig-iron and steel previously described, but with this practice other problems arose which certainly were coincident with, if not a direct result of, hard blowing.

PROTECTION OF FURNACE HEARTH

The first furnace was provided with a steel bosh jacket externally cooled with water sprays. This gave no trouble except at the juncture with the mantle, but this was remedied with a row of short cooling plates. The hearth protection, however, was entirely inadequate. It consisted of a 12-foot, rolled-steel jacket, lined with cast-iron, water-cooled staves—a very common practice in this country at that date. The hearth at the tuyere level was protected with an externally cooled cast-steel jacket with one row of bronze cooling plates above the tuyeres. The first lining used came from the United States and was from a brick company known to have produced blast-furnace brick which were usually very satisfactory.

In a few months after blowing in, however, the hearth jacket began to work hot and a number of iron "breakouts" occurred on each side of the iron notch, under the cinder notch and under the side opposite to the tap-hole as well. A large number of staves were cut, but in some places the iron passed under these coolers. This was true of those at the rear of the furnace.

Upon blowing out, none of the original hearth blocks could be found, and there was a very deep salamander. The hearth wall for the most part had been reduced to 12 inches of original brickwork, but it had disappeared entirely at certain points where the iron had come into contact with the staves.

Just at this time the second blast-furnace was under construction. It was entirely of Australian material, as previously mentioned, and no heavy rolled sheets were available for use in the construction of hearth jackets and, in fact, no shops in the country were equipped to fabricate such material.

The use of sea-water for cooling purposes made the use of iron or steel cooling pipes about the furnace undesirable, hence it was decided to give up the cooling staves and to make the hearth jackets for the new furnace of cast-steel, and the same design was adopted in repairing No. 1 furnace. These jackets were 16 feet long and six inches thick.

The writer felt convinced that even with hearth jackets of this design some internal cooling would be necessary, as otherwise the jackets would be perforated almost as readily as the rolled-steel plate and staves first used at this plant; hence, to provide this internal cooling, a modification of the system of hearth cooling used by Mr. F. H. Foote at South Chicago was introduced. During the 'nineties, this method of cooling had successfully kept in blast at the South works of the Illinois Steel Company several old furnaces with very inadequate hearth protection as compared with present-day practice, one of these stacks making a million tons of iron in one lining after blast of over seven years.

The practice adopted by Mr. F. H. Foote was to drill holes down into the hearth wall inside the plate jacket to a depth of from two to three feet below the tap-hole, and to insert a ¾-inch pipe to the bottom and connect it with the water-supply. In case water went into the hearth so as to be troublesome, the holes were filled with cement and redrilled.

The modification adopted in Australia consisted of incorporating copper cooling pipes in the hearth wall. These pipes extended to the bottom of the jacket and were set at an inclination, so that the bottom turn of the pipe was about two feet from the hearth jacket. This hearth protection and cooling proved very satisfactory, but an improved arrangement would, it was thought, be secured by placing the pipes vertically and close to the jacket; the pitch-line or distance between pipe centers to be 12 inches. This design would provide effective cooling under the cinder-notch and on each side of the tap-hole, where additional cooling seemed to be necessary.

BOSH PROTECTION

The boshes of furnaces 1 and 2 have the external cooling, and, while the bosh jacket corrodes very rapidly, it will last out a blast and seems to assist in maintaining uniform furnace work. These furnaces are equipped with Baker and Neumann distributers.

In No. 3 furnace an error in the construction of the turning cylinder reduced the throw of the distributing bell from 92 to 66 degrees, and the wear on the furnace inwall was uneven. In the construction of this furnace a departure in the form of bosh protection was introduced.

A change of bosh cooling was thought necessary for this larger furnace on account of the corrosive action on blast-furnace linings experienced in the smelting of Iron Knob ore; hence an 18-inch brick bosh was decided upon, with a liberal supply of cooling plates, and the whole bosh enveloped in a 2½-inch, cast-steel jacket, the plates being held securely in openings provided for them. This protection proved to be entirely adequate, but much more expensive than a plate jacket with external cooling, without any apparent advantage to compensate for the extra cost.

UPPER INWALL SUPPORT

There is one other detail of blast-furnace construction which is a feature of Australian design, and that is the practice of supporting the upper 20 feet of inwall and armor plating from the blast-furnace shell, thus making it possible to remove the lining of the "belly" of the furnace without disturbing the upper inwall. This is an important matter in Australia, for the armor in use so thoroughly protects this part of the lining that, so far, the length of the life of this part of the furnace has not been reached.

The next problem is to secure the maximum life of the lining immediately above the mantle, and tests are being made with and without cooling plates to determine this matter.

SUMMARY

The noteworthy features of construction and practice in Australia are as follows:

Reduction of coke handling to a minimum by use of inclined coke bench and narrow-gage coke hoppers.

Protection of furnace hearths with copper cooling pipes laid in the brickwork.

Protection of the bosh wall with a cast-steel jacket carrying bronze cooling plates.

Support of the lining of the blast-furnace at three points—at the bottom, at the mantle, and with a secondary mantle ring under the upper inwall.

DISCUSSION

A. C. FIELDNER, *Chairman*:* The paper is open for discussion. Mr. Baker gave a most interesting paper on the construction and operation of a blast-furnace under unusual difficulties. It is no easy matter to attain success with a coke of 19 to 20 per cent. ash content and so friable that special methods in handling between the oven and the blast-furnace must be adopted. Did the friability of the coke materially increase the blast pressures in the furnace?

DAVID BAKER, JR.:† The general pressure was around 15 pounds. Before the change in coke handling was made we did not experience any very heavy pressures, but the coke dust seemed to be cumulative. I happen to know something about that because I was blowing the furnace at the start and the furnace would work along beautifully for about two weeks with no high pressure and make pretty fair tonnage, and then perhaps in five minutes it would bring a ring all the way down and drop like a curtain in front of the tuyeres.

We then changed the coke handling and there was a remarkable change for the better. We had made around 400 tons, and then we dropped to under 300 as this dirt trouble appeared, or as the lines of the furnace made this trouble. They patched up the mantle, putting a new hearth in the furnace and changed the coke handling, and within the second month after the furnace went in blast again it made 520 tons, averaged around 520 tons for one week, and made around 500 tons for the next month, which is quite a change from what it had been doing.

W. H. SMYERS:‡ I was just wondering whether Mr. Baker could answer a couple of questions about that coke. Not being at all

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†With David Baker, Consulting Engineer, Philadelphia.

‡Inspector and Chemist, Duquesne Slag Products Co., Pittsburgh.

familiar with a coke of as high an ash as 20 per cent., I was wondering if he could tell us the chemical analysis of that ash. Would it be as high as 50 per cent. silica, and was it unusually high in alumina or iron?

DAVID BAKER, JR.: The ash was extremely high in alumina and we had to add silica rock at first to bring up the slag volume, but our silica rock was high in alumina, also, and we got a pretty heavy viscous slag. The ore runs about 2 to 2½ per cent. silica. We did not have too much slag either. I can not give you the exact analysis of the coke ash, but it does run unusually high in alumina. There is no question that that made a good deal of trouble.

W. H. SMYERS: Do you recollect about what sort of burden you used; that is, how much limestone, coke, and ore?

DAVID BAKER, JR.: We used about 12,000 pounds of coke and, as I remember, about 16,000 of ore, and 4000 pounds of stone.

A. C. FIELDNER, *Chairman*: The difficulty in handling viscous slags in this blast-furnace reminds me of the trouble we had in the United States Bureau of Mines about thirteen years ago when we attempted to operate an experimental slagging gas-producer. The ash of the coke contributed a high percentage of alumina to the slag, and high alumina content causes high viscosity. It was necessary to charge into the producer a certain amount of blast-furnace slag, along with the coke and limestone, in order to keep the producer operating and be able to tap off the slag.

S. L. GOODALE:* There may be some interesting questions there in the very small amount of slag, even though the coke does run low in sulphur. I wonder if you would say a little about that.

DAVID BAKER, JR.: The coke runs about 0.47 sulphur, which is extremely low, and there is none in the ore and the sulphur question is negligible in the furnace. On the question of adding slag volume, it was not a matter of handling the sulphur at all; it seemed to be a problem of lubricating the furnace. If we went down below a certain point in the slag volume, it did not work evenly.

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S. L. GOODALE: Was the slag very rich in lime?

DAVID BAKER, JR.: No, about 1 to 1.20.

S. L. GOODALE: How about the magnesia; was it higher?

DAVID BAKER, JR.: No, very low.

E. H. CAMERON:* I would like to ask the speaker why the plant was located so far from the base of supply.

DAVID BAKER, JR.: On account of the coal. The coal fields were right at Newcastle. The coal seams run every which way under the city of Newcastle and although at the time we started the plant they were mining farther back, still that was the nearest seaport within twenty miles at the most, and, inasmuch as the coal would be the heaviest tonnage, they located near the coal fields.

L. C. FROHRIEB:† You stated that the brick lining for your blast-furnace which was brought over from the United States did not last as long as it should have done. What was the particular reason for this? It could not have been ordinary wear and tear.

DAVID BAKER, JR.: One very good reason for the destruction of the hearth lining was the high manganese. We had an unfortunate error on the part of the chief executive of the company who had charge of getting the ore to the plant for starting up. Instead of getting the lowest manganese ore he could, he got some of the highest, and we had, as I remember it, up to five per cent. manganese in the iron. With a new furnace, and a clay for stopping the tap-hole, which showed very good heat tests and seemed to be all right but would not hold the furnace any more than cotton wool, we had several days of pretty destructive work at the start. Finally, we located a clay that was satisfactory. We had several kinds, but the one we picked first, while it stood the greatest heat, would not stand the slag. It cut right out. The trouble was the high manganese at the start. They shipped that high manganese ore in at the start for political reasons. They were

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†Federal Engineering Co., Pittsburgh.

so eager to get that furnace going that they insisted on going ahead regardless of conditions.

A. C. Fieldner, *Chairman*: Was it possible to reduce the ash content by washing this coal?

David Baker, Jr.: Yes, but the ash was thought to be useful to provide the necessary slag volume. Cleaner coal, coked in high-temperature ovens, would doubtless produce stronger coke, but the trouble was that when the plant was built there were two companies considered for the coke-ovens—Koppers and Semet-Solvay. Both of them had to handle the job through the English company. Koppers did not have anybody to send out and Semet-Solvay actually put the plant up and then used the Belgian brick. The English concern did not use any silica brick at that time, so we had clay-brick ovens of the old-fashioned recuperator type, and we could not get the temperatures that would have been possible with silica-brick ovens. Using wet coal in these ovens would have put us out of business immediately.

A. C. Fieldner, *Chairman*: Lower temperatures would probably be used in coking than is the practice in this country.

David Baker, Jr.: Yes, much lower.

A. C. Fieldner, *Chairman*: Was the coal not blended?

David Baker, Jr.: They used three or four different kinds, but these were all high-volatile coals. It is a high-volatile field. Some of the coal is good coking coal, and some of it is very poor. In southern New South Wales there is some low-volatile coal, but it is quite a haul. The practice has recently been improved by relining the ovens and putting in silica brick.

B. R. Shover:* Some of the experiences related by Mr. Baker recall similar things at other foreign blast-furnaces. Indian coke also has a high ash content—about 22 per cent. on the average—and is soft and friable. Its action in the furnace differs, however, from that of the Australian coke in that 10 pounds was the maximum possible

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blast pressure. At nine pounds, the furnaces operated regularly and easily, slips were unknown, and the quantity of flue dust, consisting almost entirely of stone and coke dust, was negligible. Except for its effect on the mechanical character of the coke, the ash was not a detriment, because it furnished material for the necessary slag volume.

A. C. Fieldner, *Chairman*: Some of the European countries have much greater difficulty in making a satisfactory blast-furnace coke from the coals available in their own countries. In the summer of 1924 I visited some of the coke-oven plants in France, in the Saar and in the Ruhr districts. In order to obtain good metallurgical coke in France it is necessary to blend several coals. In this manner good mechanical strength is obtained in the coke and the density is suitable for blast-furnace use. However, in many of the districts even such blending is not sufficient to obtain a strong and dense coke. It is necessary to pack the coal closely in charging molds. This is done by grinding the coal fine, and then charging it into a rectangular mold of the same shape as the coke-oven, while a number of vertical stamps are dropping down on the coal to pack it tightly in the mold. This cake is then pushed into the coke-oven in about the same manner as the coke is discharged.

At the Saar mines, the coke-ovens have no low-volatile coals available for blending with their high-volatile coals. To use the high-volatile coals alone results in a weak and porous coke. Experiments were therefore made on preparing an artificial low-volatile coal by carbonizing high-volatile coal at low temperature in Salerni retorts. These retorts consist of horizontal cylinders, a series of four, in two rows of two each. The crushed coal is agitated by an internal stirrer of the screw-conveyor type. Since the coal is non-coking, it does not agglomerate, but remains in a granular form. As it goes out of the retort, it is fed onto an endless belt by a mixing wheel, where it is mixed with coking coal in the proper proportion and charged into the coke-ovens.

The low-temperature char contains about 16 per cent. volatile matter and is about the same as our Pocahontas coal. When mixed with about 60 per cent. of high-volatile coal, it gives a coke of excellent density. This experimental plant supplied one or two coke-ovens in the battery. Several papers have been published describing the operation of this experimental plant and the yields of tar and by-

products obtained. The process has not yet reached the commercial stage. With the letting down of international trade barriers, it would be much cheaper to ship a low-volatile Ruhr coal into the Saar than it would be to make the artificial low-volatile coke.

B. R. SHOVER: I would like to have a little clearer idea of the cast-steel bosh jacket. Was it used in connection with ordinary coolers, or was it water cooled for a thin lining?

DAVID BAKER, JR.: It had pockets, very similar to what we have in this country, usually made of plate steel, with pockets for the coolers to go through. They just simply cast it in sections.

SMALL STEAM-TURBINES*

By George A. Orrok†

Turbines are usually classed as "small" when the horse-power developed does not exceed 750, but this classification is only comparative. When turbines developing 250,000 horse-power are under construction, it might be good practice to regard turbines of 2500 to 3000 horse-power as small. However, neither number of stages, pressure drops, nor non-condensing regimen can be used as a criterion, so it is better to stick to the arbitrary figure which has perhaps become a standard. Small turbines are of many types, but may be classified both by the construction and by the method in which the steam is used in the wheel. In the DeLaval type the steam is expanded in the nozzle and is passed once through the buckets of a single wheel. This was the first successful turbine, and it has been used to a great extent. It naturally leads to high bucket speeds and in the small sizes to a very high speed of rotation, in some cases higher than 12,000 r.p.m. In order to make the turbine a usable proposition, a special reduction gearing was developed for reducing the speed to a proper point. Some years later in Germany the Riedler-Stumpf turbine was developed, in which the steam, having been expanded in the nozzle, was passed through the wheel buckets a number of times by a number of return channels situated behind the jet.

In America, Terry, of Hartford, provided ventilating return passages, improving this machine to a considerable extent, and this type of machine has been largely built in America.

In the Curtis type a wheel is provided with two or more sets of blades and the steam is used a number of times on the same wheel, each velocity stage using a portion of the jet velocity.

In the Electra, or Westinghouse type, the steam, having passed once through the buckets of the wheel, is caught by a return passage on the opposite side of the blade, which returns the steam to the wheel on the discharge side and passes it through the buckets in the reverse direction. Turbines of a somewhat similar type have been made by Dake and other manufacturers in this country.

In the Kerr type the buckets are made almost exactly similar to those of the Pelton water-wheel, and the steam is used only once in a

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set of buckets. This necessitates a number of stages when economy is to be secured.

The original buckets of DeLaval were symmetrical impulse-type blades with a projection at top and bottom, forming a housing. The earlier machines had disks made in halves with the dovetailed roots of the buckets held firmly between them; but DeLaval found that the floating shaft with the disk revolving on its center of gyration was of such value that the solid disk was soon used with the blades dovetailed in axially—a much more satisfactory construction. Our first DeLaval turbines of 300 horse-power, purchased in 1893, had this type of wheel, and on test developed a brake horse-power on 17.35 pounds of saturated steam. The steam pressure was 155 pounds, and the vacuum 25.6 inches. The cycle efficiency in this test was 51.2 per cent.

The Reidler-Stumpf and Terry machines were invented at about the same time. The buckets were semi-circular in shape and were carried at a small angle to the circumference of the disk wheel. Stumpf cut his buckets out of the solid, but Terry used a built-up wheel of saw steel—a very excellent construction and well suited to his shop. Both Terry and Sturtevant are now using the milled-out solid wheel. The Stumpf return nozzles were milled out and similar in design to the buckets, while Terry's were built up of bronze single castings, ventilated in the center and bolted together.

In the Westinghouse type the buckets were milled out of the disk or inserted in a dovetail and were symmetrical, the return passages being pear-shaped channels in the plane of the pitch-circle of the blades.

The Curtis blades, symmetrical at first, were soon turned slightly, making the discharge angle a little flatter than the entrance angle, while the fixed blades were usually duplicates of the moving blades. The Rateau blades are nearly duplicates of the Curtis, but the nozzles are longer.

The Kerr buckets were drop forged, inserted into the drilled and milled slots, upset in a press and turned off smooth. Kerr's entire design was developed to suit his boring mills and to make an assembly job. He designed four sets of units, from which 20 sizes of machines could be assembled, and four long bolts held the machine together. He also used saw blanks for disks and converging nozzles. Most of the other manufacturers followed DeLaval in using a diverging nozzle.

All small turbines have been partial-entry machines, ordinary machines being throttle governed, but the better and larger machines may be nozzle governed. Only a few machines are full entry with throttling governors, following the practice in larger machines.

Casings are almost always symmetrical, with two exhaust nozzles to avoid right-hand and left-hand machines, the Kerr machine alone sticking to an axial exhaust after all others had given it up. Many manufacturers have developed pump and blower units in which both driver and driven casings have been combined, thus two-bearing and three-bearing units are common. Thrust-bearings and flexible couplings of excellent design are used. Governors are mostly plain centrifugal governors mounted directly on the shaft end, while on the larger machines the Jahns governor or similar types, on the same shaft as the oil-pump and driven by worm-gears, are in vogue. Emergency-stop governors are also provided. Bearings are almost always ring coiled and require very little attention, although in the earlier machines they were placed in too close contact with the casings and were often thrown out of line by heat-expansion strains.

Many of the later small turbines, however, are designed along Rateau lines, and multi-stage machines are now common. In general, the type differences are becoming much less marked as the earlier patents expire and are thus thrown open to general use. Most of these machines are now built in from one to eight stages when of larger size or when used condensing, the largest units showing more of the characteristics of the large turbine.

By far the largest use for the small steam-turbine is auxiliary work where the turbine runs non-condensing and its exhaust is used for heating the feed-water. In the earlier central stations the auxiliary power required usually ran about three to four per cent. of the total power, and the heat in the exhaust was just about sufficient to heat the feed-water to 212 degrees F. Economizers were rarely used and regenerative working had not become general. The use of the turbine for this purpose blended in well with station design and no steam was wasted. The auxiliary power consequently was attained in a highly efficient manner.

With the increase in size and economy of central stations, as well as the raising of steam pressures and improvements in economy of the auxiliaries, the quantity of exhaust steam became more than sufficient

to heat the feed-water, and electrically driven auxiliaries came into use, especially where economizers were installed.

To-day, when regenerative feed heating by bled steam from the main turbines has become general, and when economizers are being omitted and air preheaters installed, it would seem that the days of the turbine-driven auxiliary were ended, but this is not so. Even while the bus system and house-turbine system of electric auxiliaries are flourishing, the small-turbine builders have taken advantage of the increased knowledge of turbine construction to produce machines that still hold their own with the electric auxiliary of either system, and indeed offer certain advantages to the designer and operator.

The essential auxiliaries at East River, the new station of the New York Edison Company, are all steam driven, as well as certain of the non-essentials which have a duplex drive. In the investigation which led to this decision it was found that the heat economy of all three systems was sensibly the same, within one quarter of one per cent. Reliability was perhaps a little better for the steam auxiliary system, since only one link—the steam piping—must be safeguarded instead of two, as with the electric systems. The first cost was also greatly in favor of the steam system, when the electrical systems were properly safeguarded.

Outside of the central stations, industrial plants which need process steam have found it much to their advantage to use turbine drive for their auxiliary machinery. In paper and sugar plants this has run into the large turbine field as well, and units exhausting at 200 pounds pressure, or less, produce a system providing power and process steam in suitable proportions at a minimum cost.

Many of the turbines are built for condensing use and many are geared, thus taking advantage of the best known ways for attaining thermal economy. Some of the best machines have many stages and in design are really small turbines; that is, large turbines built down in size, as many as 40 stages being used.

One of the machines, made by Tosi in Italy, is of 500 horse-power, of the Parsons type, and gave an economy on the test blocks, condensing under 200 pounds pressure, of about 11 pounds of steam per horse-power. The Brown-Boveri Company has machines of this type also with about the same water rate. Loesel machines with 40 stages have also been built, but information is wanting as to water rates.

The earlier machines would give cycle efficiencies of 30-40 per cent.; the better machines to-day go to 50 per cent.; while the best small condensing machines exceed 60 and approach 70 per cent. The surface-volume ratio is still too high for the better efficiencies possible with the larger machines.

Fig. 1 and 2 indicate the characteristics of very small and moderately small steam-turbines. Fig. 3 shows Rankine cycle efficiency ratios, and Fig. 4 gives a record of the water rates at the East River station of the New York Edison Company.

Taking all things into consideration, the small steam-turbine is a most advantageous piece of apparatus. It is light and occupies a very small space. It is rugged in construction and automatic in operation. It is economical in the use of steam in proportion to the price you pay for it. It has no depreciation nor serious repairs. It requires little attention, and uses little oil. It maintains its economies over a series of years. The first small turbine which I installed ran seven years without examination, and there are in operation to-day machines which were started up more than 15 years ago, and on which no money has been spent during that period. Machines are built of

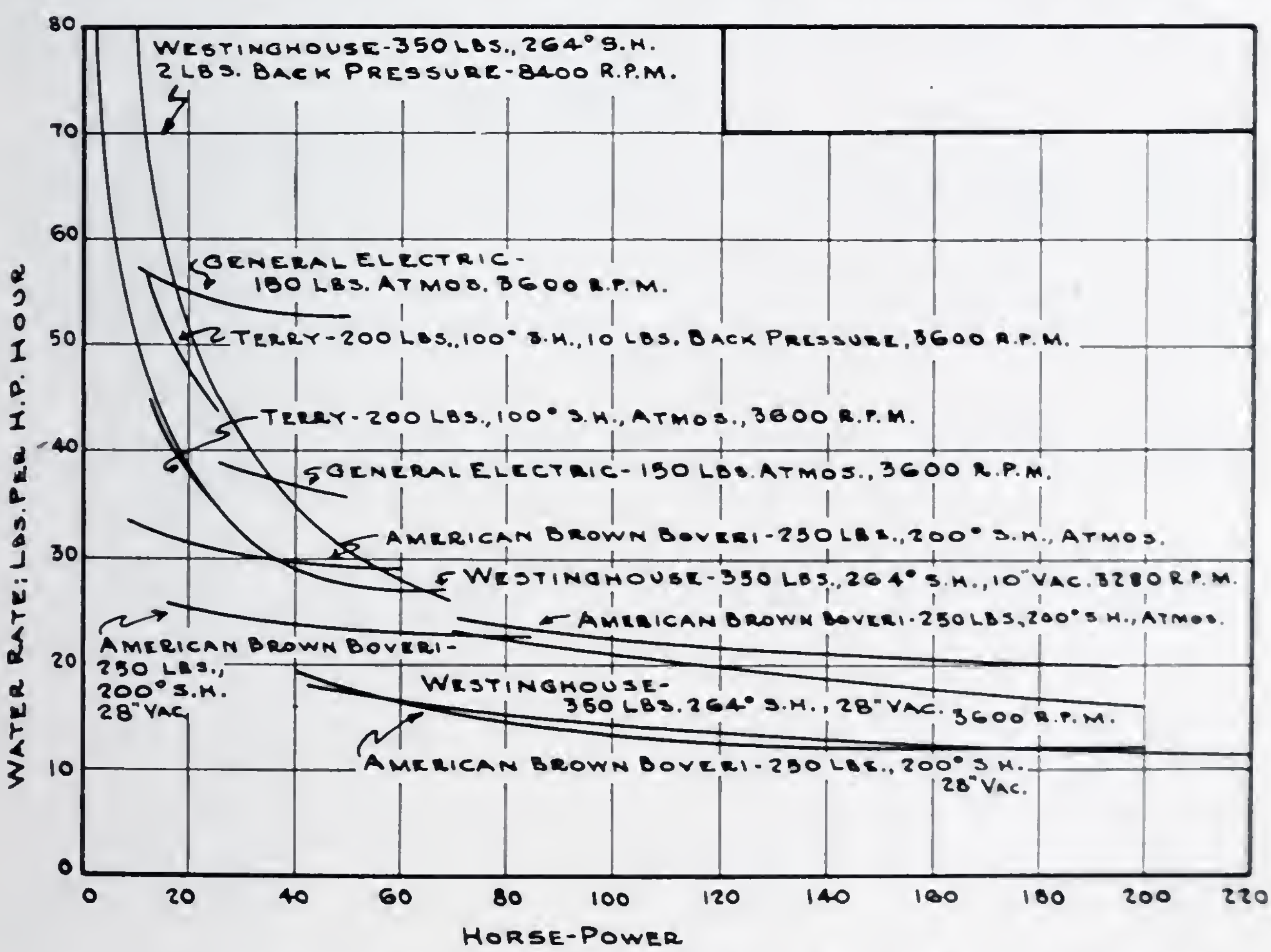

Fig. 1. Characteristics of Very Small Steam-Turbines, Condensing and Non-Condensing.

every type, for every condition, and for every kind of service, and we may say that the small steam-turbine is a worthy successor to the steam-engine.

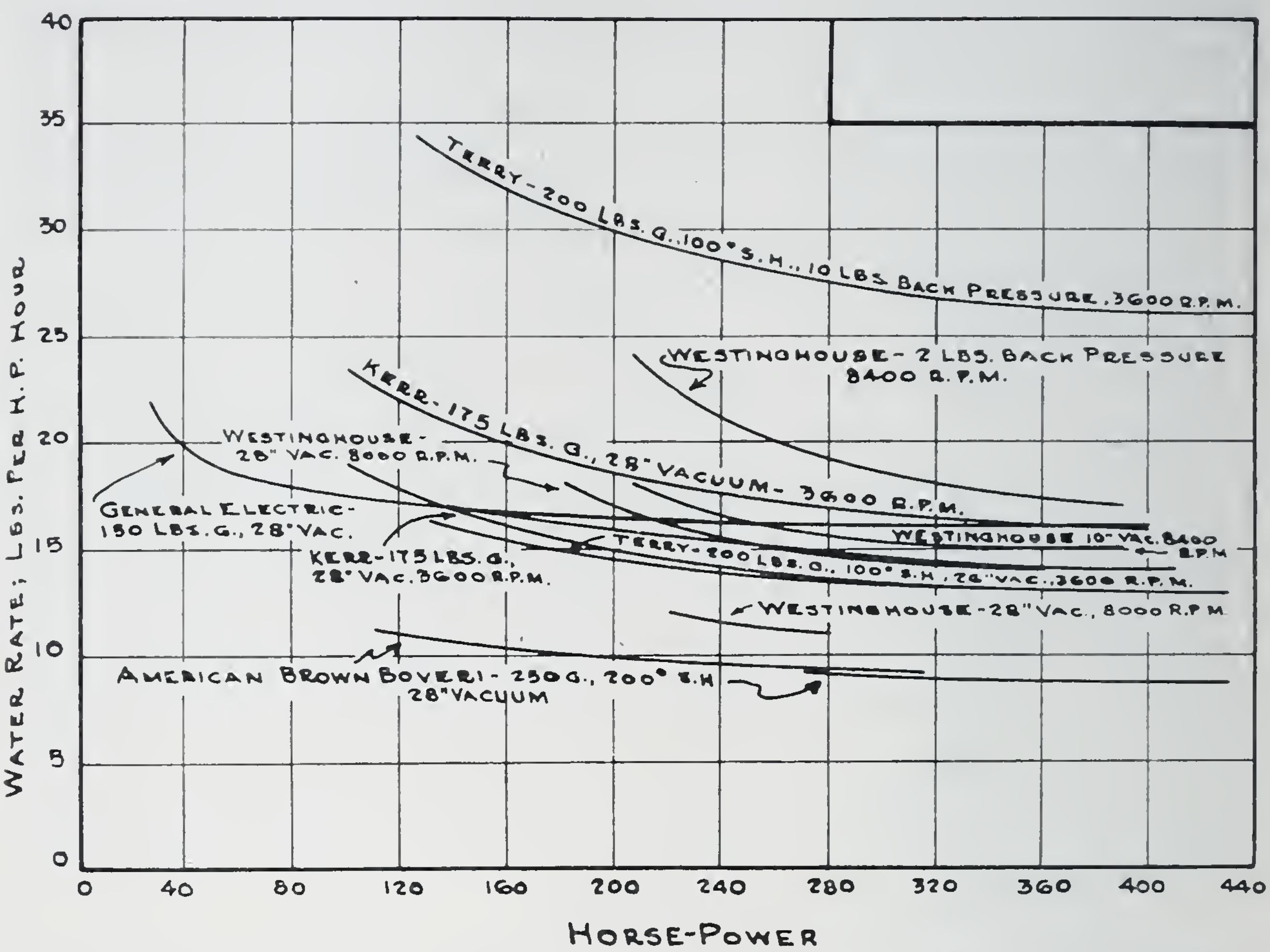

Fig. 2. Characteristics of Moderately Small Steam-Turbines, Condensing.

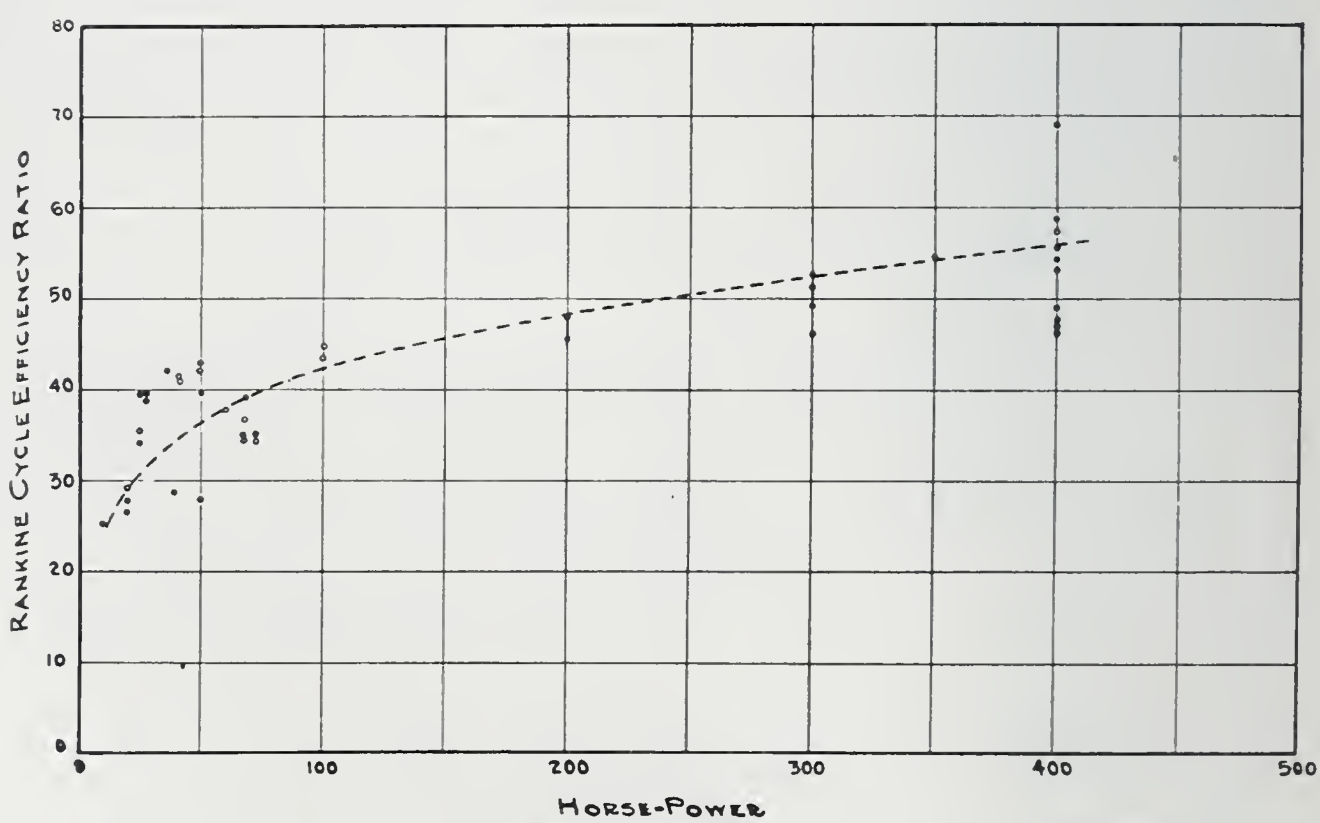

Fig. 3. Rankine Cycle Efficiency Ratios for Small Steam-Turbines.

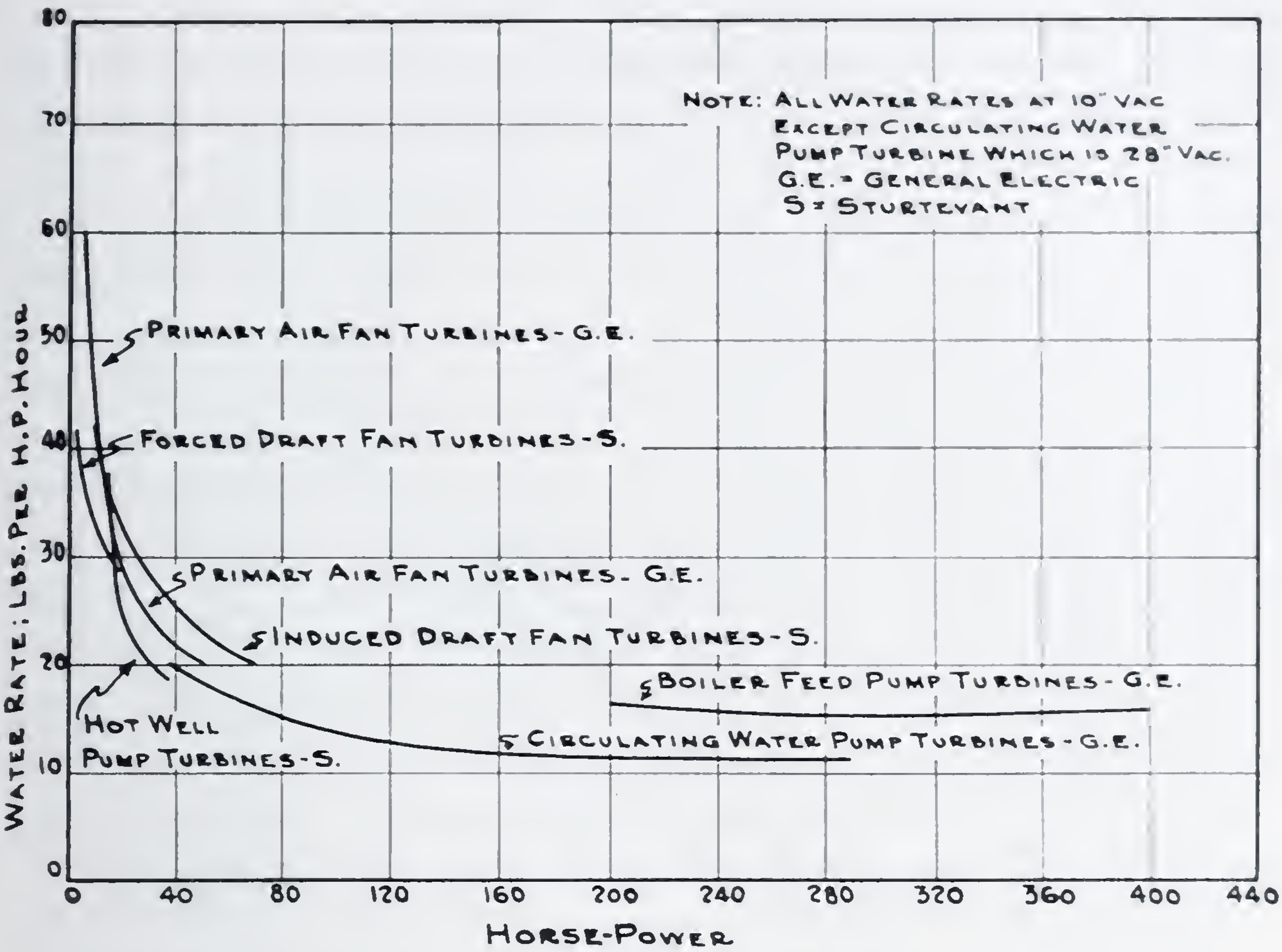

Fig. 4. Water Rates of Steam-Turbines.

DISCUSSION

W. D. Canan:* I would like to ask a question particularly in regard to the speed of small turbines. Several manufacturers put out machines in which the speed is from 6000 to 8000 r.p.m. Are such high rotating speeds objectionable from the operating standpoint?

George A. Orrok: Not if the wheel is strong enough not to go to pieces?

W. D. Canan: Is there any difficulty in manufacturing wheels to stand that speed?

George A. Orrok: None of the designers will offer you a wheel that is not mechanically strong. I told you about Terry, who put them on a machine and speeded them up to 5000 r.p.m. to make sure that they would not explode. He said if they would stand the

*Rust Engineering Co., Pittsburgh.

5000 r.p.m. he knew they would never come up to that speed in actual service, and I think most of the manufacturers to-day are speeding up their wheels and trying them out under high speeds to make sure that they are actually safe. The bladings are becoming better and better. We do lose a wheel once in a while, but the wrecking of a small turbine, while it is not unheard of, usually comes from some other thing than the wheel itself going to pieces. I remember the wreck of a Terry turbine. The trouble was that two of the bolts which held the return passage had in the course of six or seven years' use loosened and backed out enough so that the ends of the bolts ripped up the edge of the blades, but the wheel was not wrecked. Sometimes pieces of steel get into our rotors, and once in a while the edges of the buckets may break off and make trouble; but we have not had a wheel go to pieces in a long time. I think you can dismiss that from your mind. I do not think any manufacturer would sell you a wheel that would be in danger of wrecking itself through speed. I think you are safe up to even higher speeds than the manufacturers recommend.

W. D. Canan: On the higher speed machines is the critical speed above the ordinary rotating speed?

George A. Orrok: On small turbines it is very rarely that you go through the critical speed. The shaft is so short and the bearings so close together and the wheel itself such that you very rarely encounter such troubles.

W. D. Canan: Didn't the original design on the De Laval pass through the critical speed?

George A. Orrok: Yes, but he made a floating shaft, and a big wheel on this floating shaft, and allowed it to revolve on its center of gyration. The original wheel that ran at 20,000 revolutions ran on its center of gyration, while the De Laval to-day runs like any other machine and is far below the critical point. It is only on the larger machines where the distance between the bearings is so great that you stand any chance of running up to the critical point, let alone going through it. I would say that not until you get up to 3000-kilowatt wheels would you get up into the field of possible critical speed.

H. C. CRONEMEYER:* I understand one of the advantages of the Brown-Boveri machines is that they require less floor space per horse-power than most others.

GEORGE A. ORROK: I do not know. They are not any smaller than any of the others.

H. C. CRONEMEYER: That is one of the claims they make.

GEORGE A. ORROK: I do not think any of the Brown-Boveri men would claim that. They have built more Parsons turbines than Parsons himself. Their designer, Mr. Meyer, is a very clever man and they know very well what they can do. They can do exactly what Allis-Chalmers, or the General Electric Company, or Westinghouse, or any other manufacturer can do. If your labor is cheaper you can build a more complicated machine that will get better efficiency; if you spend your time on polishing you will get a much better machine. I remember one time Mr. West of the E. P. Allis Company told me how he spent a week polishing up the piston heads of a pumping-engine and when he ran the test he got an extra quarter-pound of the water rate, which paid a bonus of $25,000. Those things can be done, but your turbine designer knows his shop and he is designing the kind of machine he can build in his shop with his tools and his men at the cheapest rate, to sell for the most money. I do not see any reason why any one turbine designer can not duplicate the water rate of another turbine designer. Whether he will do it or not depends on a lot of other conditions, and I do not believe that anybody can say that this make of turbine is better than that make. I do think that you can make the statement that this particular machine is better, but you can not say that the Allis-Chalmers turbine is a better turbine than the General Electric, or that the Brown-Boveri is better than the Westinghouse, or that the Terry is better than the Kerr. You can say that this particular machine will give better efficiency than another, but they are all within a limited range. The other part is the shop, and what it costs to build it and what they can persuade you to pay for it.

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WILLIAM SHAW, *Chairman*:* I believe you mentioned the fact that in the design of the East River station no economizers were provided. What were the influencing factors in omitting economizers?

GEORGE A. ORROK: We are not going to bleed so much steam and it works out that it pays us to do it. We are going to use air heaters, which we have to use under our conditions, so when we figured out what was left for economizers it was too small to be worth while. We will have 60 or 80 degrees which might go into an economizer, but for that small amount of temperature raise in the feedwater it would not pay to install it.

WILLIAM SHAW, *Chairman*: What is the anticipated normal temperature of preheated air at the East River station?

GEORGE A. ORROK: You ask me in a year or so and I will tell you. What it will be I do not know. We figured on delivering the air at between 400 and 500 degrees. It is too soon to say what we will actually do. This is the first time we have attempted a scheme of this sort. There will be adjustments and changes and after we learn the results we may make further changes.

MAX HECHT:† Is it merely a question of economy that keeps down the efficiencies of these small turbines? There are certain industrial uses where perhaps a 24-hour 75 per cent. load factor with very high efficiency would be economically advisable. Can we expect that in the future there will be more effort put on designing these small turbines of 100 to 500 horse-power to give higher efficiency?

GEORGE A. ORROK: You can get a small turbine to-day to give you 70 per cent. efficiency. If you get up to 2500 kilowatts, you can get 80 to 82 per cent. on a non-condensing machine. That is better than anything we have done with a big machine. If you can afford to pay for it designers can give you what you ask for. Naturally the purchaser can not afford to pay for it, or does not consider it worth while, so there has not been any serious demand for machines more

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†Chief Chemist, Duquesne Light Co., Pittsburgh.

efficient than around 50 to 60 per cent.; but the early DeLaval machine of 300 horse-power gave 51 per cent., and that was in 1893. They can give you whatever you are willing to pay for up to the maximum lines. The turbine business is well understood to-day. Turbine designers know what they can do and what they can not do.

J. M. Lessells:* I presume the problem in this country as contrasted with Europe is vastly different. You have here high labor costs and very much cheaper coal and probably are not concerned as much with efficiency as they are in Europe. You mentioned small differences in steam consumption, but I noticed these were probably as much as 50 per cent. Do you consider that a small difference?

George A. Orrok: It is small if you count in the cost of the oil, which is a very serious thing just now. Let me make a statement. There are only two stations in the whole of Europe that are doing better than 20,000 B.t.u. per kilowatt-hour. You gentlemen know how many stations we have in the United States that are doing better than that. We have about 35 of various sizes.

We did not put in economizers because they cost too much, and because our work is usually run on a pretty low load-factor, and economizer costs go up in this case and we have not been able to make it pay. In newer station work we have used steel economizers, which means you have to heat the feed-water to 280 or 300 degrees before it goes into the economizer.

You have a problem in which you have half a dozen different factors. If you use one you will not use another. Between them all you pick out that combination of factors which will give you the lowest cost. There may be three or four solutions to the question and the one you pick out may not be quite as good as some other one, but it may offer advantages in operation.

B. R. Shields:† Has the development of the governor valves and governing mechanism of the small turbines kept pace with the development of the unit itself? From our experience it would seem not. While we have had no turbine trouble due to the wheels or

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†Superintendent, Springdale Station, West Penn Power Co., Springdale, Pa.

blading, we have had considerable trouble with the governor valves when operating with high pressure and superheat. In the small turbines this trouble has been principally due to excess wear of the valve, and consequent lack of good governing. Governor valves which are installed in a horizontal position and are not operated by the oil pressure have been more or less a failure with us. We want a small turbine in which the governor is powerful enough and which will control the unit should it lose its load, either by dropping the load or by breaking the coupling. One manufacturer said that they had never been asked to supply a turbine that would do this. In the larger units, the trouble has always been due to sticking throttle-valves and sometimes the governor valves. This has been due apparently to the growth of the metal. Units which have been running six or seven years must have the clearance increased in the balance cylinder of the throttle-valve about once a year, due to the growth of the metal.

George A. Orrok: What pressure and superheat do you have?

B. R. Shields: We use 335 pounds pressure, and 200 degrees superheat.

George A. Orrok: Do you have a good strainer in front of these valves?

B. R. Shields: Yes.

George A. Orrok: The manufacturers should be able to supply you with good valves if you demand it of them. They know enough about the development of valves, and can get the proper material for them. I have not heard of any sticking valves for several years, and do not see why you should have any particular trouble with the growth of the metal if it is the proper metal.

BOILER SETTINGS*

By G. E. Dignan†

There have been a great many interesting and valuable papers written regarding refractories and conditions in boiler furnaces. These papers cover the make-up of refractories and material used in boiler settings and cover the temperatures and certain other operating conditions in the furnaces. I do not believe that it is necessary to go into details of the manufacturing methods, the analysis of refractory materials, or the conditions to be met in boiler furnaces. The purpose of this paper is to try to point out how conditions can be met in a practical and common-sense manner.

In discussing boiler settings, we are more concerned with the larger installations, as the conditions are more severe and the lessons learned can be applied with profit and discrimination to the smaller installations.

In view of the fact that the cost of boiler settings is rapidly increasing in proportion to the cost of the boiler proper, it behooves us to consider carefully the design, the materials used, and the method of application, and to make sure that the costs of boiler settings are not out of proportion to the contemplated savings due to higher operating efficiencies and ratings. Each setting should be considered as a separate problem, the materials selected with all possible care, the installation made in proper fashion, and a careful study made of probable operating conditions.

When it is possible to calculate probable temperatures and fuel conditions, the problem is more simple than where the operating and fuel conditions are apt to run wild. One point to be carefully considered is that the operation should be kept within the proper bounds of maintenance of setting. While this may sound rather like an admission of failure on the part of the designer of boiler furnaces to keep pace with the designer of fuel-burning equipment and boiler equipment, we should realize that there are certain limiting factors, and high rating operation should be somewhat held in check until furnace design will permit increased rating. The condition is there and it must be borne with until means are found to improve the condition.

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To burn up an expensive setting for the sake of a fractional percentage of rating is certainly poor economy. We must not be so occupied in chasing after the last B.t.u. as to forget all about efficiency in other respects.

The big boiler furnaces are costing more than the boilers. They take up a great deal of costly building space, and the first cost is something to consider carefully in view of the loss to operation when a big boiler unit is shut down for repairs. Every effort should be made to select material best suited for the purpose. Laboratory tests are relative, and the information given by laboratory tests should be carefully considered, as the materials in service develop under conditions hard to simulate in the laboratory.

Failures due to increased furnace temperatures are seldom evidenced by fusion or sufficient melting to allow the brick to run, but the higher temperatures increase enormously the rate of attack by slag, the amount of vitrification and susceptibility to spalling, the amount of deformation in the parts supporting appreciable load, and shrinkage or distortion causing leakage through the setting. Refractories very seldom fail by fusion alone, so that it is necessary to consider all the characteristics in selecting a brick.

While the present opinion seems to be that laboratory tests are not of great practical value, at the same time they must be valuable as a method of comparison; otherwise, our selection would be more haphazard than ever. In one instance, as a basis for selection of fire-clay brick, we had standard laboratory tests made on brick from 12 different plants and then, selecting three brick which showed up best in the laboratory tests, used a different brand on each of three boiler settings. One brick was made of Pennsylvania clay, one of Kentucky clay, and one of Missouri clay. Physical tests on the three brands showed that all three were suitable for the purpose intended; and, in addition to the chemical and physical analysis, the report showed the comparative cost. All three brands were the same price at the brick plant, but, as the boilers were located in central Pennsylvania, naturally the Pennsylvania brick were the cheapest delivered on the job. Using a lump-sum cost of all brick and shapes required, and the cost of Pennsylvania brick as 100 per cent., the Kentucky brick cost 106 per cent. and the Missouri brick cost 127 per cent., the difference in cost being practically the difference in freight rates, there being a

slight variation in cost of the special shapes. After three years' operation, we have not been able to find any appreciable difference in the wearing qualities of the three brick. The boilers are 1500 horsepower each, and they are operated continuously at a base load station of 250 per cent. of rating. As a result of this experience, and many other similar experiences, we have selected a number of fire-brick which we feel are better than the average, and we buy the brick with the lowest freight rate, as the plant prices are all the same.

There are on the market several brands of refractory brick which will withstand higher temperatures than the so-called standard first-quality fire-brick. These are very high in price, and it is yet to be found that the greater expense is justified except in some cases where the higher refractory materials have shown long life and have apparently justified the high first cost. We have not found that the general use of these high-priced refractories is justified, and most power-plant operators and designing engineers have yet to be convinced that the higher cost of these refractories is an economical proposition. We feel that, with proper design and operation, most any of the standard first-quality fire-brick will be satisfactory within the limits of a refractory lined boiler setting.

The refractory manufacturers have educated most of us to believe that the standard nine-inch fire-brick should measure 9 by 4½ by 2½ inches, and most of us have that size in mind when we refer to a standard fire-brick. To date, the Refractories Institute has not specified a size for standard brick, and according to the recommendation of the Institute a shipment of fire-brick should be accepted by the purchaser if a certain percentage of any one shipment falls within the tolerance specified. Some of the manufacturers are trying to hold their brick to a standard weight of seven pounds, and others to a standard volume of 100 cubic inches without regard to dimensions; consequently, we may expect to get brick of all sizes and shapes, as the different clays have different unit weights. It is necessary that we know the kinds of clay to be used before designing the settings, particularly if the nine-inch fire-brick must fit between special shapes and between castings or other appliances in the furnace setting.

If each refractory manufacturer can make most of his brick to fall within certain tolerances for his particular brand, it seems to me

he should be able to hit somewhere near the dimensions of 9 by 4½ by 2½ inches.

We have found by actual experience that we can save money in mason labor if brick and shapes are very uniform. Consequently, we will buy a uniform-size brick, and in the natural course of events the manufacturer of uniform brick will find it easier to sell his products. Unfortunately for the smaller manufacturer with insufficient money to equip his plant with the necessary machinery for making uniform brick, the price of the uniform brick is the same as the variable-size brick. If our specifications are uniform and insist on a certain size of brick, I believe the manufacturer will make his product so we will get what we want.

In selecting fire-brick, careful attention should be given to the character of brick to be used. Most of the good brick are made in soft burn, medium burn, and hard burn for each of the steam-pressed, hand-made, power-pressed or dry-pressed brick, and it is usually safe to follow the manufacturer's recommendations for the kind of burn and method of molding brick for the purpose intended.

The United States Navy "master specifications" for fire-clay brick allow on a brick of four inches, or over, a variation of not more than ¼ inch per lineal foot from any specified dimensions or approximately ⅛ inch in width and thickness and 3/16 inch in length on a nine-inch brick. Specifications have been written and brick have been made to the folowing tolerances:

> "All straight fire brick shall have the following maximum dimensions, length 9 in., width 4½ in., thickness 2½ in., and the variations tolerated shall be as follows: length 3/32 in. plus or minus; width 1/16 in. plus or minus; thickness 1/32 in. plus or minus; all fire brick shall have square sharp edges, plain faces and parallel sides. The joints shall not exceed 1/32 in. in thickness, and furthermore, each brick shall be ground if necessary and rubbed in place to insure a tight setting."

While it is possible to fulfil this specification, it means considerable expense, as the workmanship is very costly and it is necessary to gage all the brick, preferably before shipment.

We believe at the present time that refractory brick are better than they have been before. More care is shown in the making than ever before, but the refractories are being used to the limit of their endurance and, consequently, development has been in method of

application rather than development in the refractory materials themselves. Commercial development of a more highly refractory material is possible, and a great deal of work is being done in this direction, but at the present time results do not seem to justify the first costs.

The use of high-temperature cement should be given very careful consideration. Most of the air-setting cements have used some sort of a binder with a comparatively low fusion point, and the tendency is for the high-temperature cement to come out at the joints between brick when under load or heat. The harmful effect of adding certain foreign materials to ground fire-clay and the good results that have been obtained by the addition of ground bats have been clearly shown in both laboratory tests and actual operation. In any case, the joints should be made as thin as possible not only to lessen the chances of harmful results arising from the difference in the character of the joint (a more or less variable quantity) as compared with the structure of the brick (a practically uniform and constant quantity), but to increase the relative proportion of good burned brick to the joint. A joint should not be expected to be more resistant to the action of the destructive influences than the brick itself, particularly if the brick has been selected with a view to resisting conditions such as the finished work will meet. If we spend a lot of time and effort in selecting a brick for a certain condition, it stands to reason that satisfaction will be afforded by a mortar made of the same kind of material as the brick.

We have had the best results with a mixture of 75 per cent. calcined finely ground fire-clay or crushed fire-brick, and 25 per cent. of finely ground plastic clay. When we can not use this mortar, we prefer to use ordinary finely ground fire-clay for ordinary fire-brick walls. We have found it difficult to use high-temperature cement containing heavy ores as the base, as the heavy ore particles settle to the bottom of the mortar box, if the mortar be kept thin enough to use as a dipped joint. A fairly satisfactory thin wash of this type of high-temperature cement can be obtained if the solution is kept boiling, but this would mean some sort of heating device alongside of each brick-mason, which is hardly practicable. Using this type of high-temperature cement with a heavy joint makes the cost prohibitive as the cement costs about $90 a ton, and a thick troweled joint requires approximately 1000 pounds of high-temperature cement per thousand brick, so that the mortar costs nine-tenths as much as the brick, which

is considerably out of proportion to the results obtained. With other high-temperature cements the difference in cost is not quite so marked, but it is considerable. The calcined raw clay mixture costs about $25 a ton and the amount required is about 500 pounds per thousand brick, making the mortar cost $6.25 per thousand brick, while ordinary fire-clay costs about $12 a ton and the requirement is approximately 450 pounds per thousand brick, thus costing a little over $3 for each thousand brick laid.

As far as the air-setting qualities are concerned, I have removed fire-brick that had been laid in the wall for several days and found that the air-setting action was effective only about half an inch in from the face of the wall. The remainder of the high-temperature cement had not set, although the remainder of the joint would probably have been set up to some extent as the furnace was fired and placed in operation till the joints dried out. Where thin walls are used, we would recommend a mortar with cementing ingredients, as it makes a solid joint which will prevent movement of air through the wall; but, as it makes a rigid structure, ample provision should be made for expansion and contraction to permit the walls to move.

After selecting good materials and paying good money for them, don't spoil them before they have a chance to get into the furnace and pay for themselves. Keeping in mind the question of joints, take care in unloading and handling brittle refractory material and preserve the nice sharp edges, because broken edges and corners mean big joints and, consequently, greater susceptibility to attack. All fire-brick materials must be protected from bad weather. The more moisture absorbed by the brick, the longer it will take to dry out the settings and the more harmful will be the effect on the material itself. Tests on weathering have shown that after exposure for six months fire-clay brick have lost from 1 to 21 per cent. in cold crushing strength, and from 11 to 28 per cent. after exposure for a year. The very strong machine-made brick showed practically no loss after exposure for six months, but some open, porous, hand-made brick, having an end crushing strength of only 500 pounds per square inch when new, were practically worthless after open storage for six months.

In designing a boiler setting, care must be taken to see that the refractory materials are under as little stress as possible. They should be kept clear of all boiler supports or of any other structures that

might set up stresses in the brickwork. It is difficult to prevent brickwork cracking as the refractory materials can not stretch or bend and, consequently, they break under movement, and provision should be made to carry brick supports and binders separate from all other structures in order to allow free movement. Suspended arches should be carried on separate supporting members and not on the brickwork of the furnace walls.

The greater the compressive load the lower the temperature of softening so, if the walls are high enough to set up an excessive load per unit area, means should be taken to support the walls in sections in order to cut down the load. The desirable way would be to have each wall unit supported on its own weight and independent of all other parts in order to allow free movement of the brick structure. In one plant where the boilers were located in close proximity to forging hammers, we tied and braced the brickwork very securely to offset vibration due to pounding of the steam-hammers. The old boiler settings in the same plant had cracked very badly and had to be replaced with the new design. In one other plant, we found that the foundation of a mill for pulverizing coal was connected to the steel supporting the furnace, and vibrations were set up to an extent which damaged the setting. After the foundations were cut loose, no further trouble was experienced. Gaseous fuels are apt to set up pulsations and unless the walls are securely anchored there will be some movement due to the pulsation of the fuel, and the furnace walls will fail unless they are securely anchored.

The proper construction of any boiler wall requires that provision be made for lateral expansion. The expansion spaces should not be too far apart, both to avoid excessive stress in the walls, and in order that these expansion spaces in the furnace walls may not present too wide an opening for flame to lick in between the brick while the setting is being heated to maximum temperature. Staggered expansion joints do not function as well as V-shaped straight joints because the load of each course of brick is transmitted to the course below it, so that the joint is, in effect, a solid wall. We believe that the straight offset joint in the wall construction is more satisfactory. The trouble with any large expansion joint is the possibility of air leakage and the difficulty of obtaining a satisfactory joint-packing material. We recommend the use of long-fiber asbestos for packing between

brick and metallic parts, and for packing expansion joints where exposed to the furnace temperature, as the powdered materials have not been satisfactory and they will not stay in place after the furnace is heated.

Up to the softening point, the brick is just as strong as when cold and, as the extreme furnace temperature affects the brick for only approximately 1½ inches back from the hot face, it is this portion of the wall that concerns us most. One of the most effective provisions for expansion we have found is to dip each brick in thin fire-clay or mortar to within 1½ inches of the furnace face, leaving the space clear of mortar but forming a small expansion joint on four sides of each brick. After the brickwork is completed, this face should be brushed so that the joints are clear, and then the face of the brickwork brushed with a thin coating of mortar to seal the joints until the furnace has reached its maximum temperature. This has been the most satisfactory joint that we have used. When I say that the high-temperature zone is 1½ inches back from the hot face of the wall, I speak of fire-brick walls which have a reasonable allowance for flow of heat through them. If the flow of heat is stopped, then the heat zone will move farther into the refractory, which condition is not desirable. For this reason, it is not good practice to build insulation in walls and prevent the flow of heat through them. The proper method is to allow the heat to flow through and to maintain a temperature gradient that will give the best working conditions for the refractory used. The heat transferred can be collected in ducts or channels outside of the fire wall and put to a useful purpose. The proper place for wall insulation is on the outside of these hot-air collectors, where it will prevent the loss of heat and still allow protection of the fire-brick wall.

Insulation, plastering or coatings on brick surfaces should not be installed until the brick surfaces are hot; otherwise, it is practically impossible to prevent the coatings from cracking.

When preheated air is used for combustion, we find we are getting furnace temperatures that are too much for the present commercial refractories and it is necessary to resort to some other method of furnace construction. This has led to the water wall, which seems to be working out very satisfactorily and apparently has justified the higher first cost. It is well to bear in mind that the introduction of a

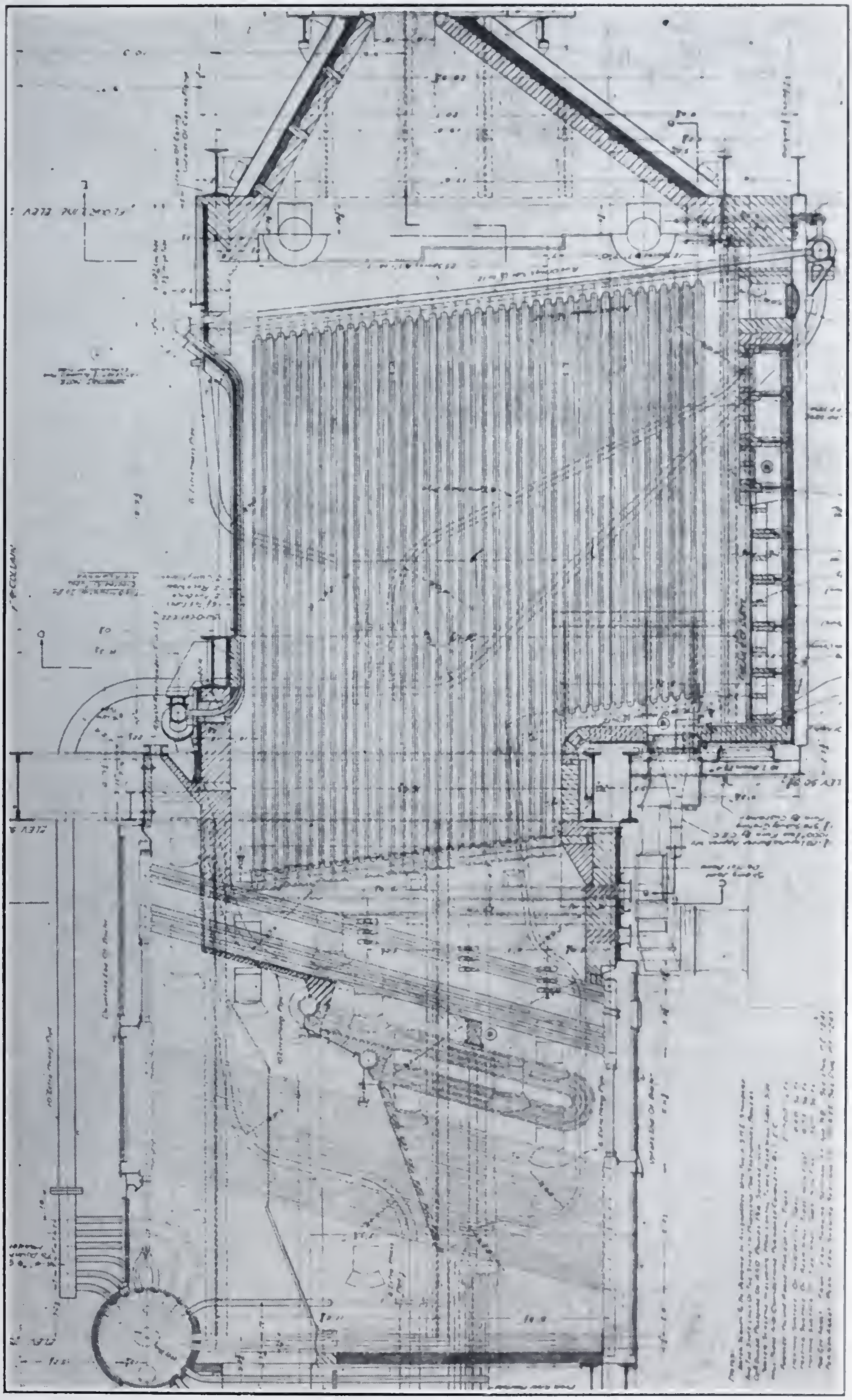

Fig. 1. Fin Furnace for Pulverized Coal.

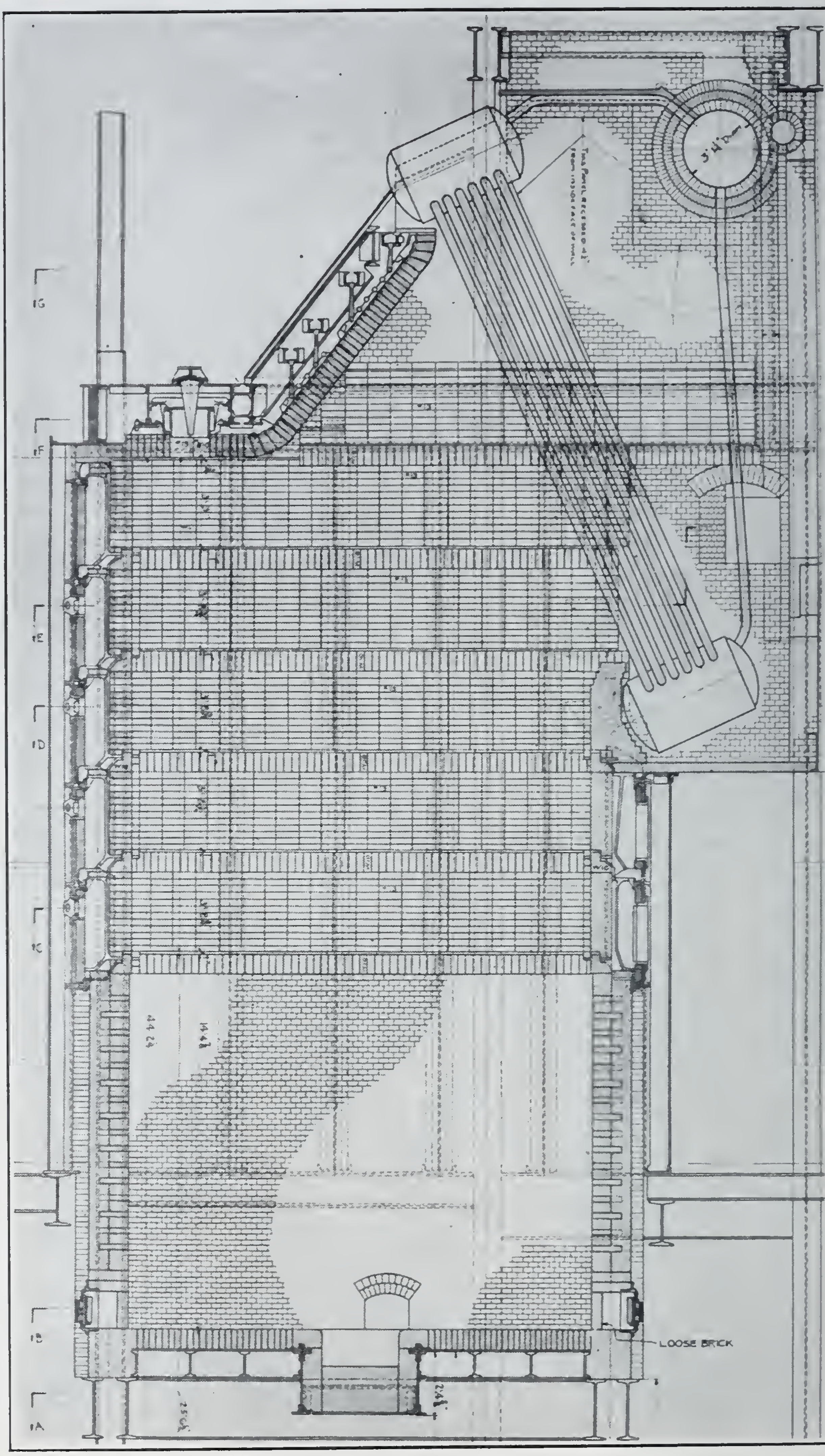

Fig. 2. Pulverized-Coal Furnace with All Walls Refractory.

limited area of heat-absorbing surface will not necessarily lessen the severity of action in all other parts of the furnace. Fig. 1 illustrates a fin tube furnace using pulverized coal. This furnace has just been completed and is not yet in operation, but is typical of this class of work. This construction is rather expensive, but from past performances the cost is undoubtedly justified. Because of the fact that the wall is protected by tubes, the refractory materials and insulation behind the tubes can be made very thin, and in this case the fire-brick were two inches thick and the insulation two inches thick. The front wall is of refractory material and has numerous openings to permit the introduction of preheated secondary air for combustion.

Fig. 2 shows a pulverized-coal furnace with all refractory walls. The upper portion of the walls is of the sectional suspended type, the exterior covered with steel plate lined with insulation 4½ inches thick. The lower portion of the furnace is solid fire-brick, using all header brick on the interior wall and getting the bond with brick 13½ inches thick. This furnace was constructed several years ago and, because of the fact that a great deal of experimenting has been done with this boiler, the furnace has been subjected to considerable punishment. At times the rating has been as high as 400 per cent., and when the boiler was first put into operation, out of a possible operating period of 10,000 hours the boiler was operated 4200 hours, in which time it was started and stopped 94 times. We believe that the durability of this brickwork is due to the use of sectionally supported walls in the hot zone and the fact that the lower wall is very securely bonded.

Fig. 3 shows the sectional wall in detail. It has sectionally supported columns of refractory tile. The tile are slipped on vertical castings with the bottom tile in each column held on the shelf formed by the casting. The upper portion of each column is sealed with an L-shaped tile which can be pulled out into the furnace to allow the new tile to be threaded on the vertical casting and with the upper part of the L to protect the cast shelf on the column casting above. This L-shaped tile is held on with a cast-iron key to prevent the tile from working out into the furnace. The horizontal space between each two rows of refractory is left open for about three-fourths of an inch to act as a vertical expansion joint, and this space is filled with a mixture of equal parts of asbestos and fire-clay. This type of con-

struction has been very satisfactory. One of the best features is that, because of each section being supported independently of the brick-work below and above it, the compressive load on the refractories is cut down considerably and this naturally reduces the tendency for the brick to fail by softening, since the greater the load, the lower the softening point.

Fig. 4 illustrates another wall construction. The load of nine-inch standard brick is distributed on special header tile which are

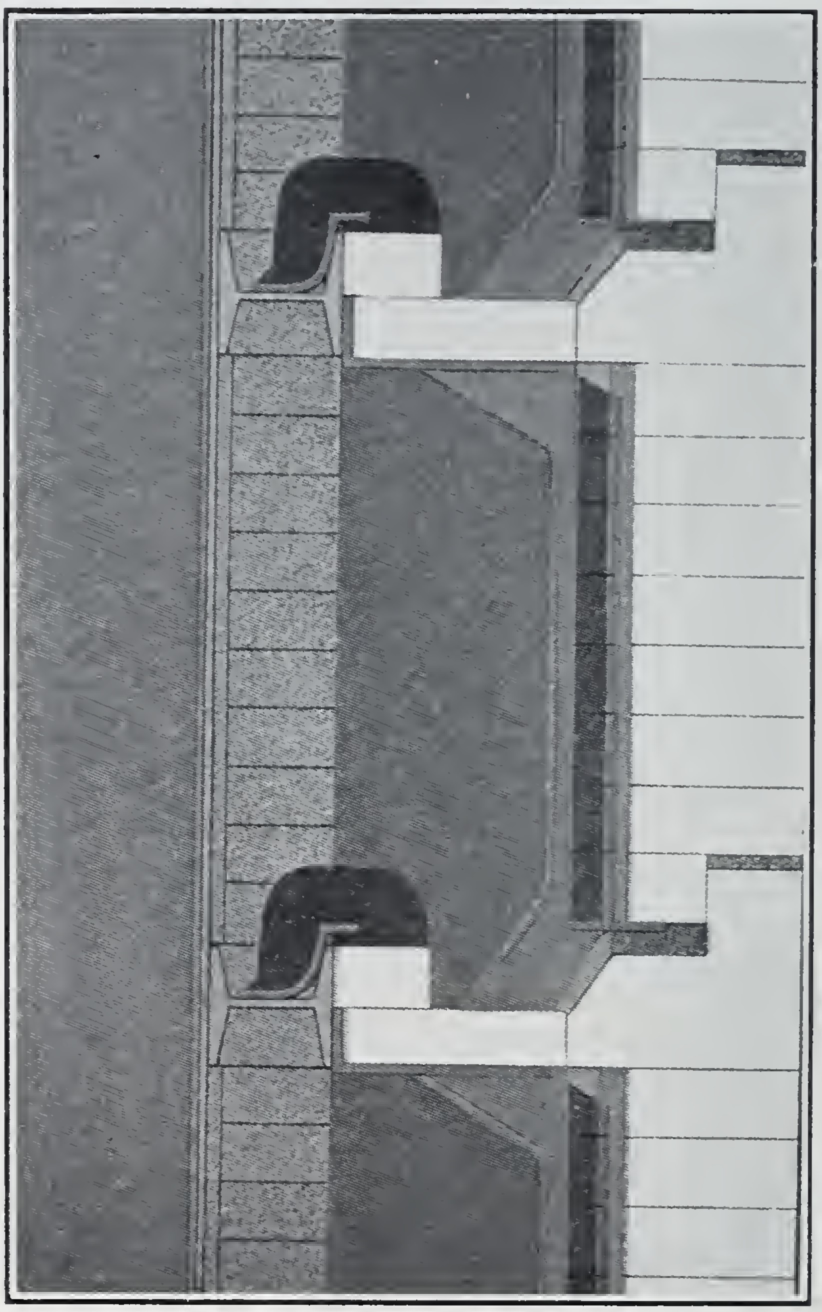

Fig. 3. Sectional Wall.

carried by specially shaped refractory blocks, used to form a pocket in the outside or colder portion of the wall; the header tile are inserted into this pocket and anchored in place by special wedge brick. The header tile extend horizontally, forming a shelf on which the

fire-brick lining is carried up to the next row of headers above. The advantage claimed is that a rigid setting is obtained and the load on the inside furnace wall is transferred to the outside wall. Each section of the wall is supported separately, and a portion of the wall can be renewed very quickly, as it is possible to renew without digging clear back into the outside wall. Ordinarily about one-fourth of

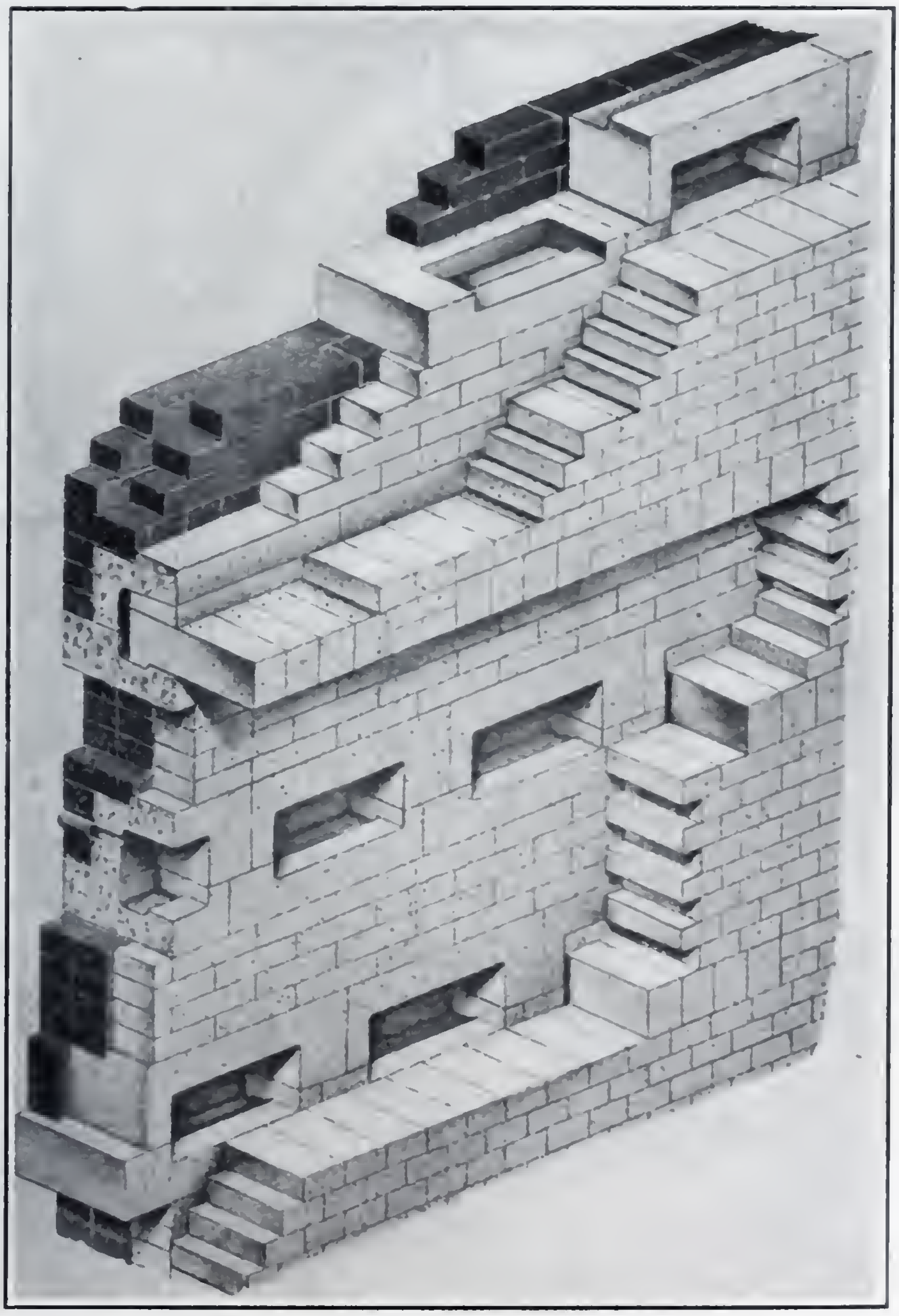

Fig. 4. Sectional Wall Supported by Refractory.

the wall is composed of special shapes and the remainder of nine-inch standard brick. The renewal is on six per cent. only, as the exterior walls need not be renewed. The disadvantage seems to be that the rigidity is not desirable, as the interior (hot face) brickwork will move more than the exterior (cold face) brick, and results have

shown in some cases that the through bonding tile have either broken off or the interior nine-inch wall has pulled away from the bonding tile. To overcome this difficulty, iron wedges, connected to the outside walls with threaded bolts, have been substituted for the refractory wedges. The cast-iron wedges were loosened when the work of

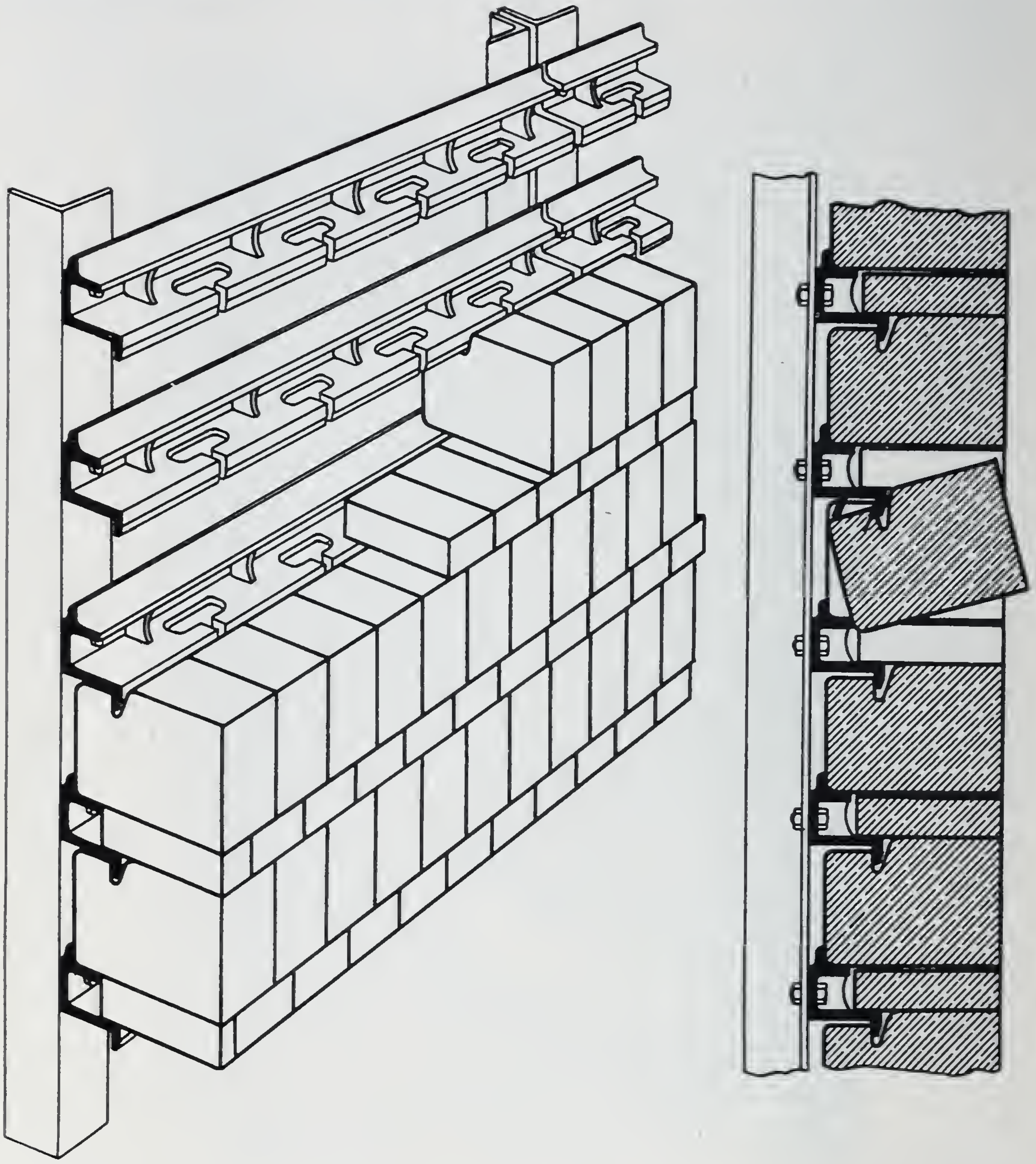

Fig. 5. Sectional Wall.

laying the fire-brick was completed, and as the setting was heated, so that the bonding tile would have some freedom of movement.

The claim made by manufacturers of most special wall construction is that any part of the setting can be replaced without interfering

with the remainder of the setting. This is true to a certain extent, but it must be borne in mind that, after the furnace has been in operation long enough to glaze or slag over the surface of the brick, it is difficult to remove one particular piece of the wall without disturbing the adjacent parts.

Fig. 5 illustrates another sectional wall. Each separate row of special tile is held in place with a casting and the space between the tile taken up by standard nine-inch brick.

There are a great many other special types of wall construction, but we believe that the three shown here are fairly representative, and we know they have been used with considerable success.

Baffles have been made with straight-edged refractory tile, or tile made with dovetailed or overlapping joints, and a great many monolithic baffles have been used. If the tile baffles are used, they should be fastened to the tubes in some manner, particularly if there is any chance of soot blowers impinging on the baffle, as the high-pressure steam will blow the baffles off the tubes. We have used angles placed on the back end of the baffle, with U-bolts clamping the tile around the tubes—a method of construction which has been very satisfactory. It is not necessary to impress you with the necessity of having the baffles tight, but selection of type is usually a question of price and personal opinion. Workmanship has more to do with the success of the baffle than the material itself, and care should be taken to see that the work is done in the best possible manner. Baffles of heat-resisting metal have recently been installed, but I do not believe they have been used long enough to tell whether they will be satisfactory from all standpoints.

Plastic refractories are valuable under certain conditions. Tests have shown that prepared samples of certain well known plastic refractories, when properly heated, give approximately the same results as fire-brick; but, in practice, it is hard to heat a thick wall uniformly. A frequent result is that a crust forms on the heated side of the wall, and it will not stand spalling as well as a good fire-brick, as the plastic refractories harden to the desired strength only upon action of heat which is limited to a comparatively small depth of the furnace wall. When used in thick layers, the plastic refractory is apt to peel off, as I have observed in several cases. Plastic refractory materials cost almost three times as much as a good fire-brick and, while there

may be some labor saving in the installation of plastics, the saving will not offset the higher cost of material. I believe that the present plastic refractory materials are best suited for patching purposes.

We can not expect to get either good material or good work unless we are willing to pay for them. No matter how well the setting is designed or how much money is spent on materials, we can not get a good installation unless the work is properly done. It is easier to pick out good materials than to get good workmen. At the present time, a good brick mason will not average much over 500 standard fire-brick per eight-hour day, so you can figure the cost yourself.

The subject of flat arches has been well covered in numerous papers and you are probably sufficiently familiar with the different types.

We find it better to use a form or centering in lining up the arch to insure a good even face on the lower side of the arch. While it is not absolutely necessary to do this, it makes a better job.

There is very little difference between the kind of refractory materials used by the different arch manufacturers. The main thing to consider is the method of suspension and the engineering service given by the arch company. The joints should be kept tight to prevent infiltration of air, as cold air striking the hot faces of the arch will cause the tile to spall. We believe the arch tile can be laid up somewhat the same as the side wall; that is, by filling the upper part of the joint with mortar and leaving the lower part for expansion and contraction.

Perforated wall blocks have been used with considerable success in the construction of boiler walls, principally for the introduction of air along the stoker lines. The use of these blocks is a problem for the designer to contend with, as the introduction of excess air must be considered.

Fig. 6 illustrates a fuel-oil furnace using a suspended wall with air space for preheating some of the primary air used in the fuel-oil burners. Instead of having an outer wall covered with steel plates, this installation uses an eight-inch course of common brick. The front wall of the furnace where the burners occur is only nine inches thick and because of the fact that the burner openings take up so much of the front wall it is very difficult to hold the refractory lining. We

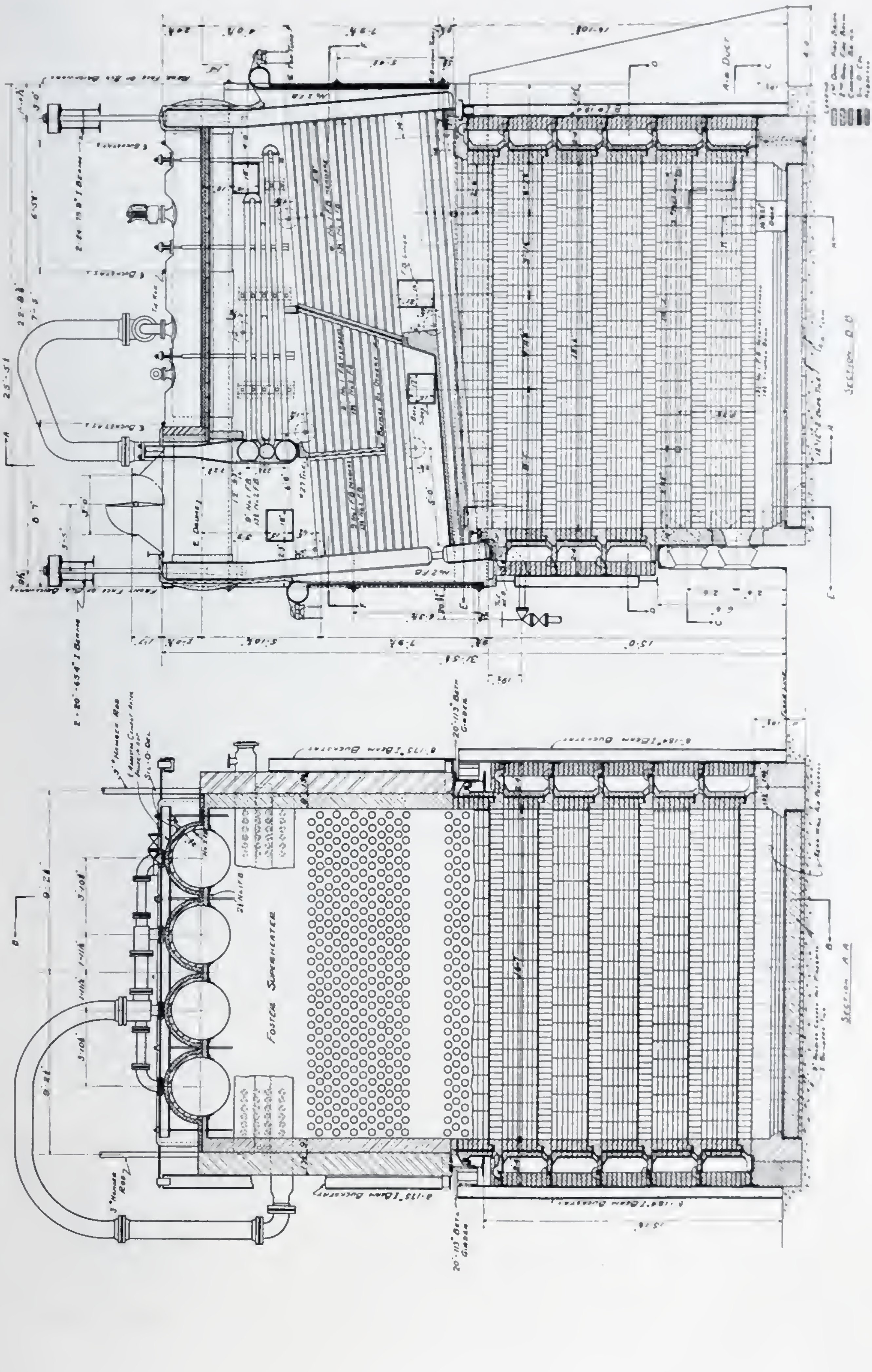

Fig. 6. Fuel-Oil Furnace.

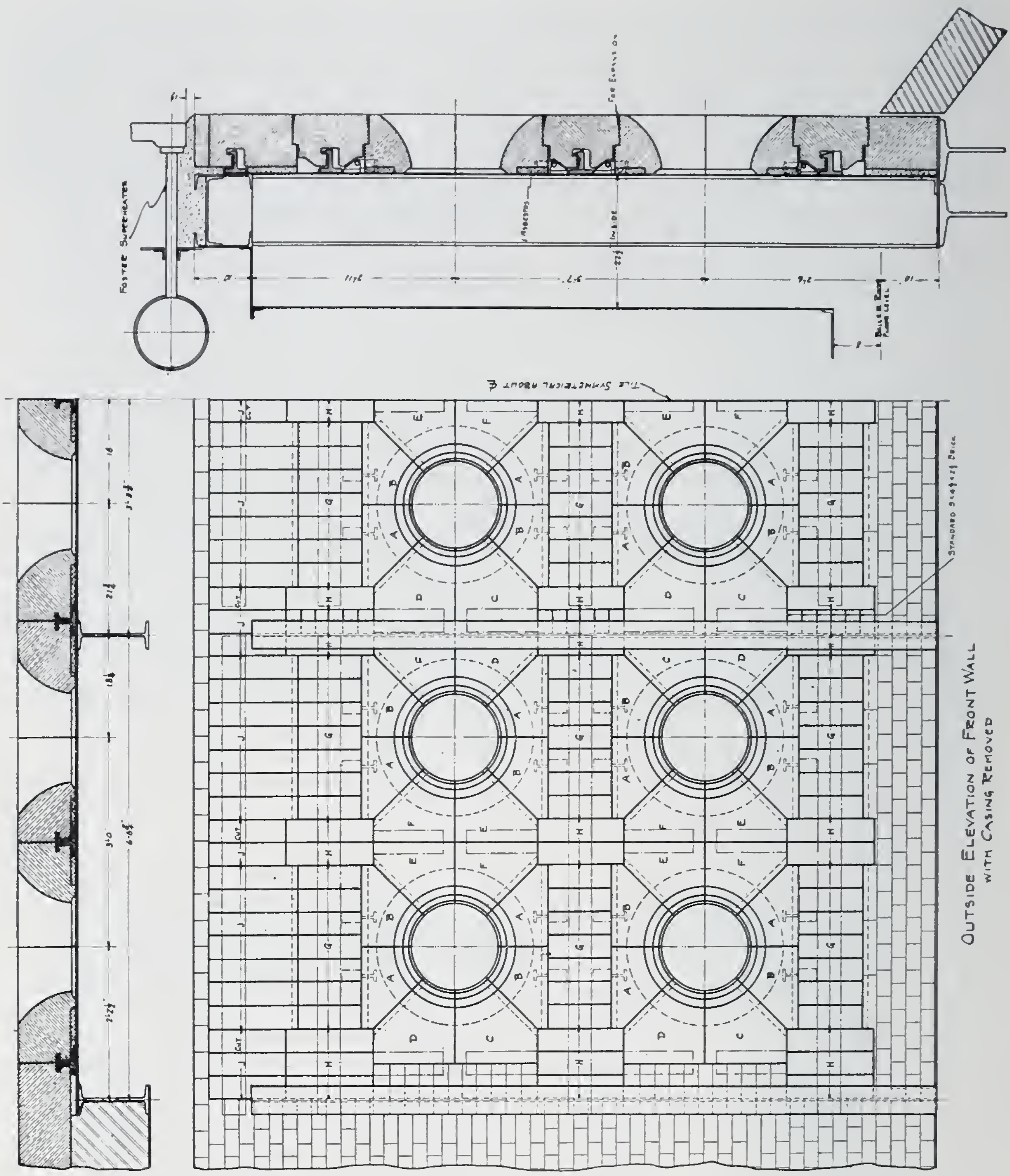

Fig. 7. Support of Refractory Lining.

have, therefore, used the construction illustrated in Fig. 7, where the wall is composed of special tile, all supported on castings.

Fig. 8-10 show three different settings for the same type of boiler. Fig. 8 shows the boiler referred to in the first part of this paper—a powdered-coal-fired furnace using longitudinal air ducts for preheating the air introduced as secondary air. The front wall was insulated with 4½-inch calcined insulating brick, while on the side walls common brick were used, with ½-inch insulating plaster instead

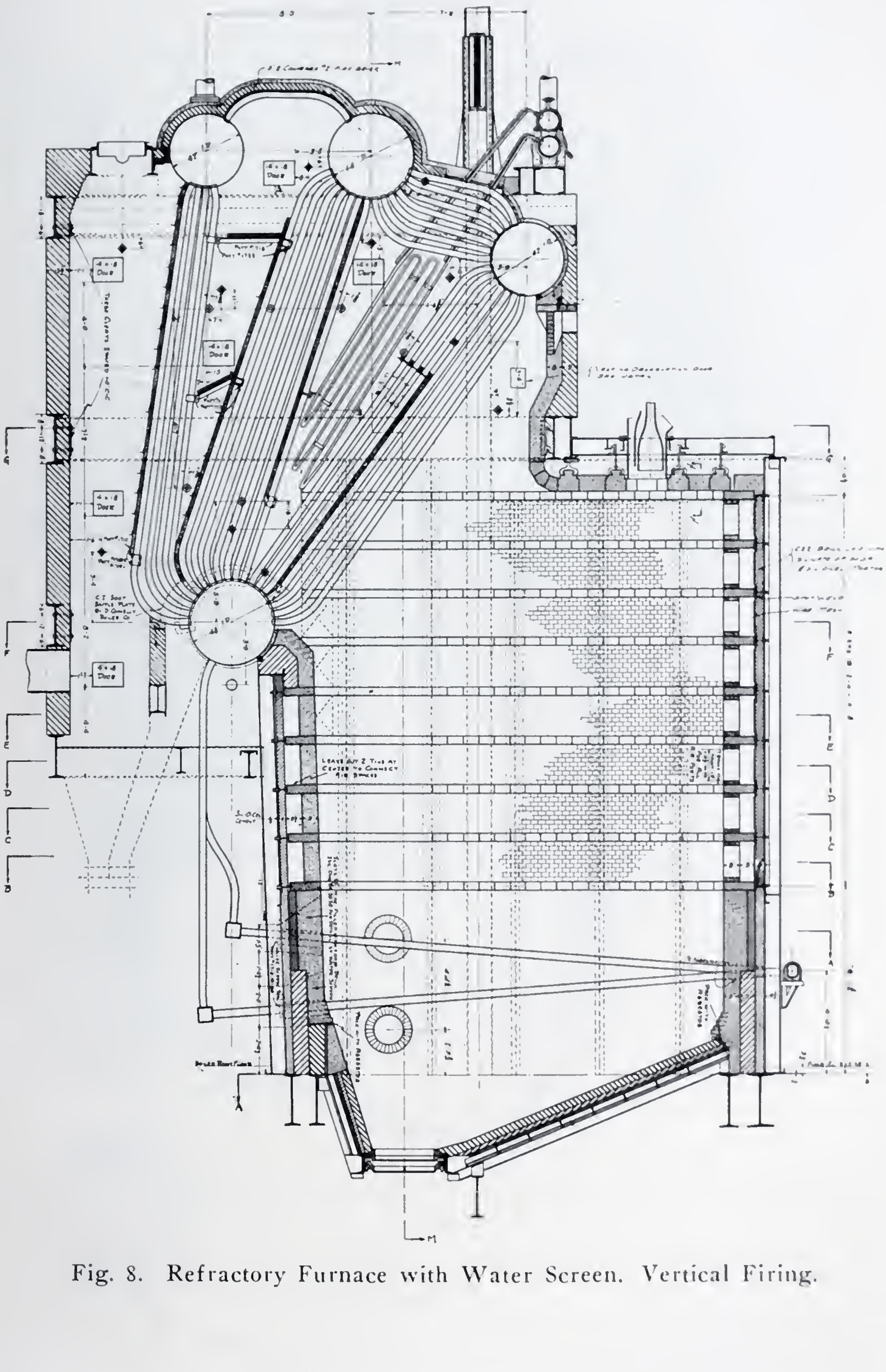

Fig. 8. Refractory Furnace with Water Screen. Vertical Firing.

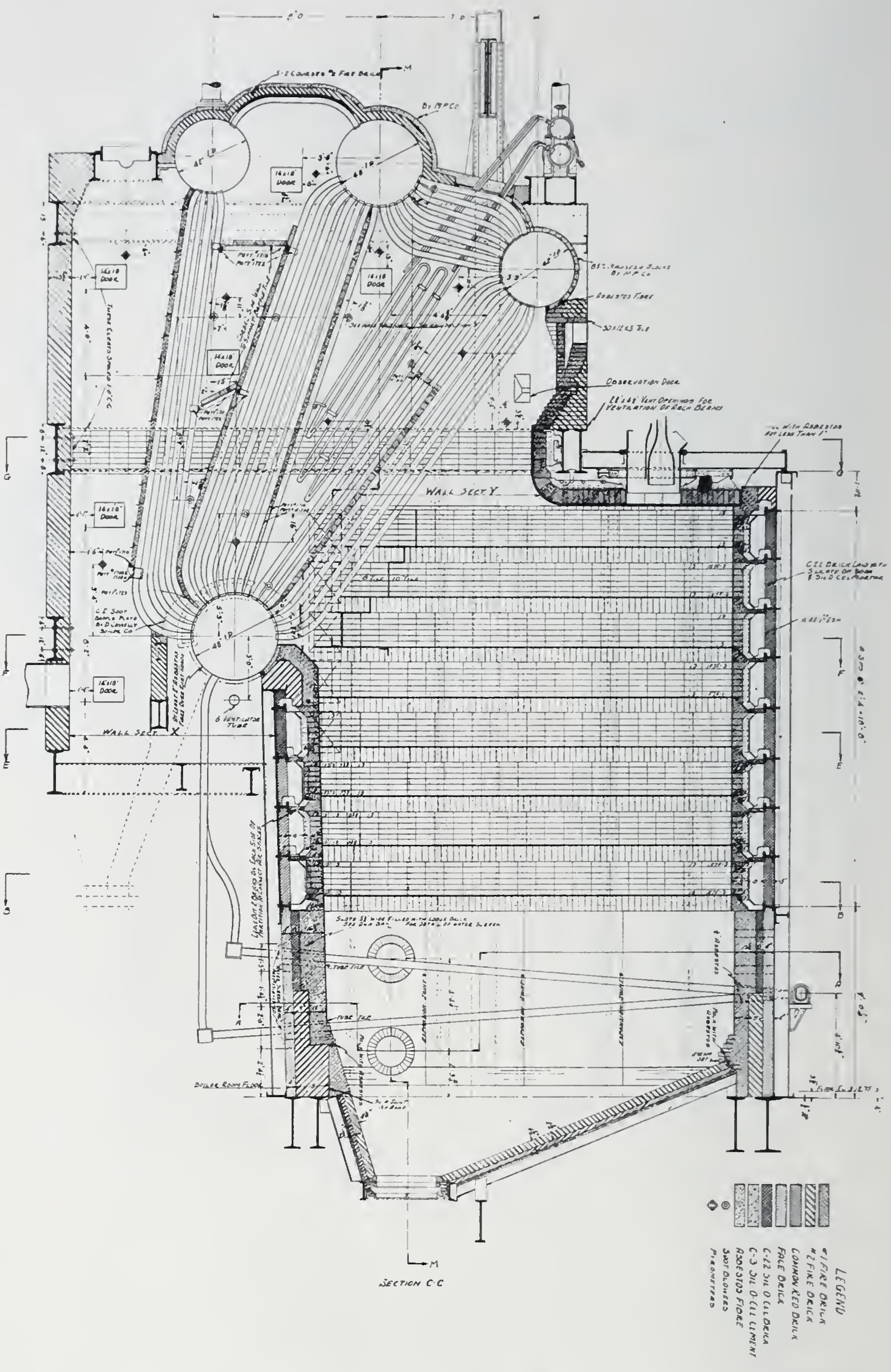

Fig. 9. Sectional Refractory Furnace with Water Screen. Vertical Firing.

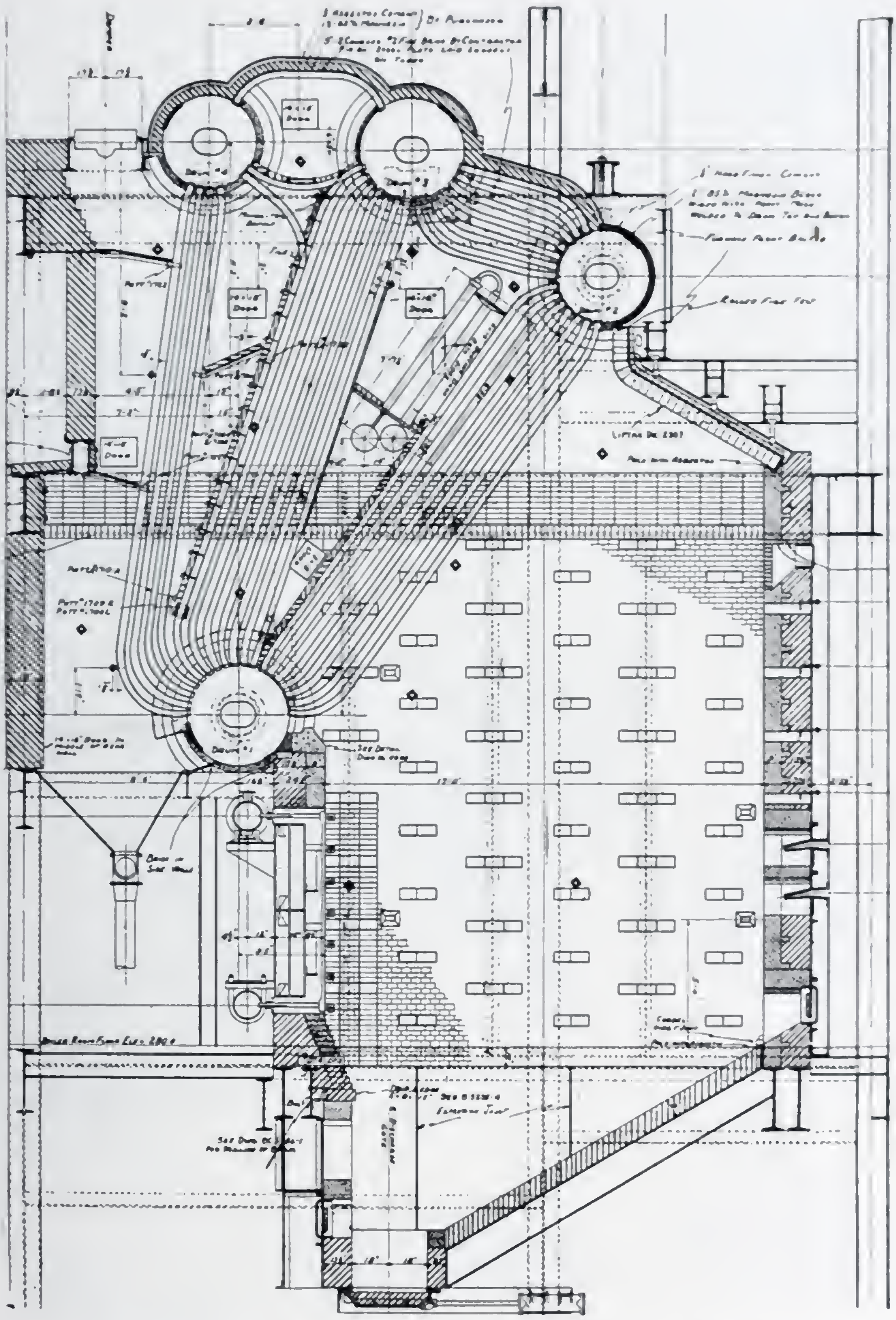

Fig. 10. Air-Cooled Refractory Furnace without Water Screen.
Horizontal Firing.

of the insulating brick, and the whole air-cooled section covered with steel plating. The common brick were used in the side wall because it was felt that the additional cost for the insulating material was not justified in the heat saving contemplated.

Fig. 9 illustrates the same size boiler at the same plant laid up with a sectional wall with insulation in the front and side walls, the

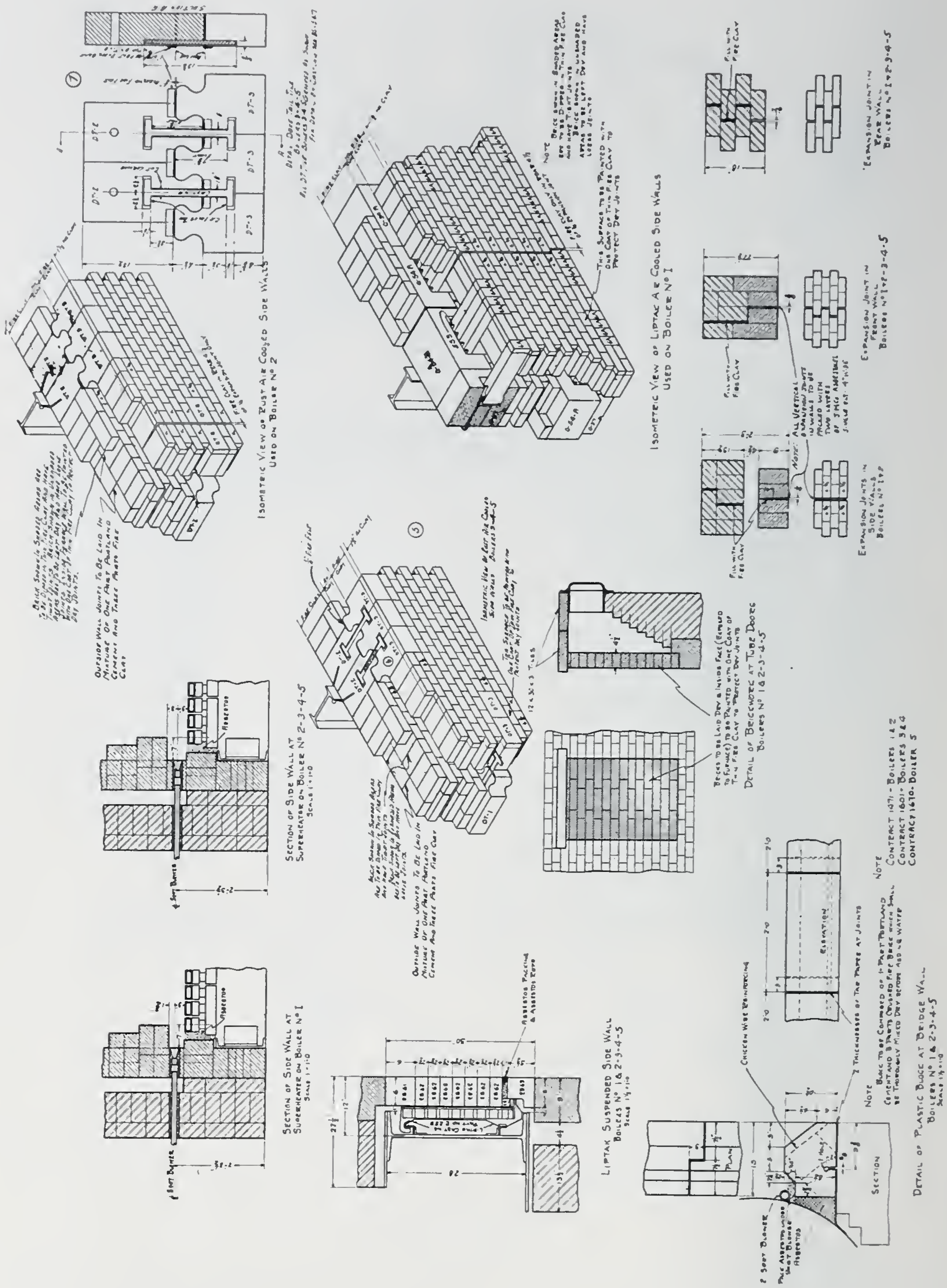

Fig. 11. Miscellaneous Details.

remainder of the setting being exactly the same as shown on Fig. 8. Fig. 10 illustrates the same size and type of boiler at another plant. This plant was originally designed as a stand-by station for a water-power plant, but conditions developed so that these boilers are now

being used continuously and are developing the same ratings as the boiler illustrated in Fig. 8 and 9. This furnace is designed for pulverized-coal firing with horizontal burners and without a water screen. The ash-pit is cooled by air which is introduced into the rear of the furnace, forming a channel of cold air which reacts to some extent on the falling slag. The wall is made of nine-inch standard brick, bonded with special tile to the outside 13½-inch wall across the 4½-inch air space. The interior wall is air cooled, with the exception of the portion taken up by the special bonding tile. Air inlet openings were made at the top of the air-cooled portion so that the flow of the air is down into the basement, where the suction of the fan for the burners is located.

Brickwork in the upper portion of this boiler is supported on 28-inch I-beams which run the full length of the furnace and are in such a position that there will not be over nine inches of fire-brick protecting the main girders. Because of this fact, special tile were used, supported on castings to prevent the tile from falling into the furnace and at the same time to give clearance between the refractory and the supporting beam for a current of cooling air.

It is sometimes difficult to form the proper connection between the lower drums and the bridge wall, and the detail in Fig. 11 shows how this has been done in several cases. A steel plate is fastened with tap bolts to the lower drum, and the upper portion of the bridge wall is formed of plastic refractory, which not only protects the soot-blower element but forms a pocket to place packing to seal the openings.

Fig. 12 illustrates the setting of a pulverized-coal furnace using the Detrick wall construction in the air-cooled portion, with Bailey cast-iron sloping ash bottom and a shrouded water-tube construction in the rear wall of the furnace. This boiler is not yet in operation, but is expected to withstand very high ratings.

In conclusion, we have to consider methods, the selection of materials, care in workmanship, and the study of the probable operating economy in regard to both output and maintenance. A good setting can be very quickly ruined by inexperienced operators. At least, the operator should keep pace with the development of materials and design and not expect too much from the facilities available.

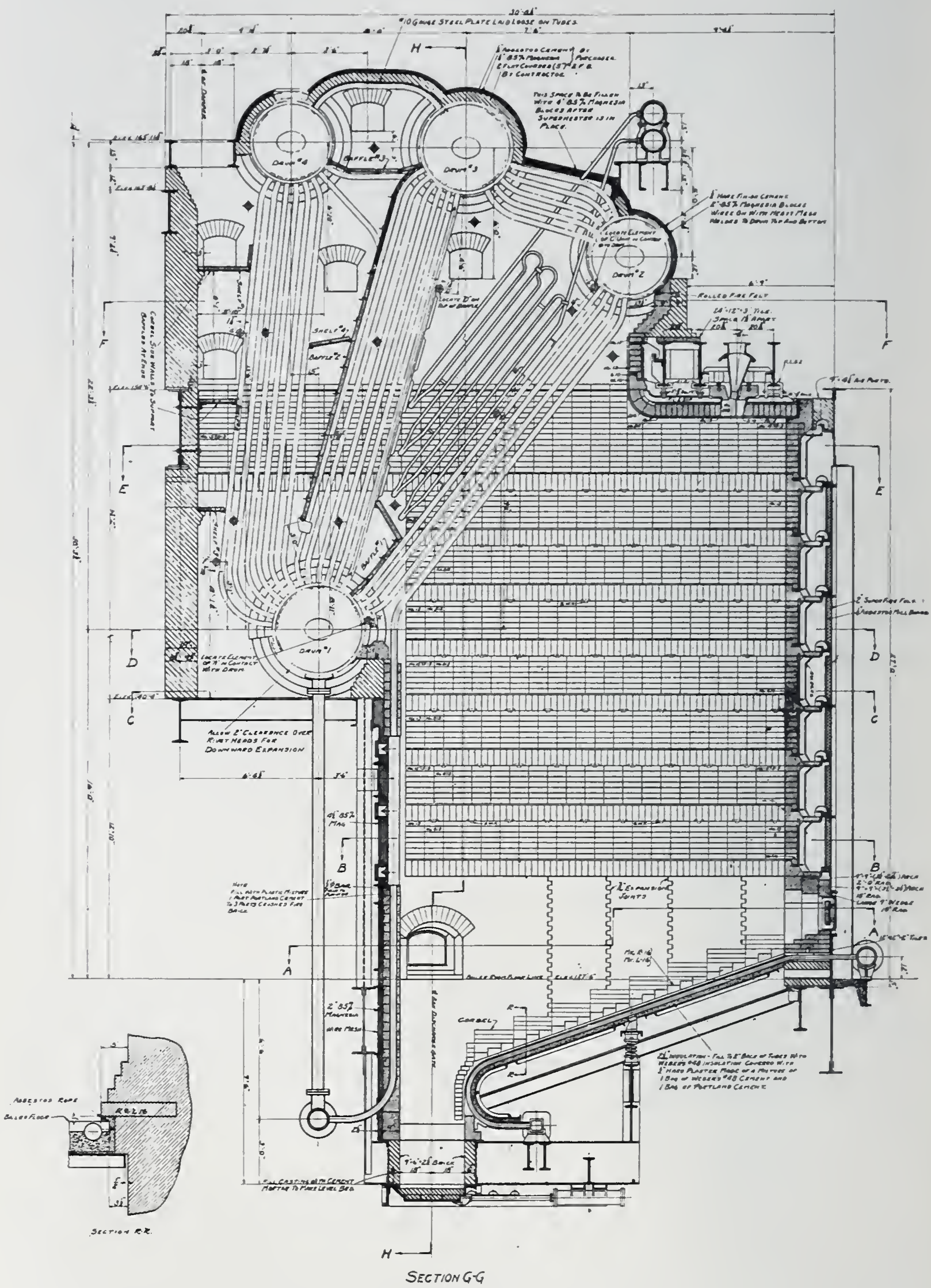

Fig. 12. Pulverized-Coal Furnace with Bailey Bottom.

DISCUSSION

George A. Orrok:* We have to congratulate the author on a very good and carefully prepared paper on furnaces built up out of refractory materials. The point that I wish to emphasize, however, is that what we want to-day is not furnace design, is not boiler design, is not stoker, or powdered-coal-firing design, but a complete design of a boiler, furnace and firing apparatus as an entity, in which the parts are so proportioned and the materials are so picked out that in the end we can get the maximum output for a given amount of money spent on the steam-making apparatus. When we were content to burn 100 pounds of coal per foot front of boiler, we could do almost anything we wanted to and we would not hurt the boiler. In those days we could get 80 per cent. efficiency, and we can do it just as well to-day. But the output from the piece of apparatus per dollar invested was very much smaller than it is now. We have been able, by the invention and improvement of stokers, to carry out and obtain 80 per cent. boiler efficiency—not superheater and economizer efficiency, but the boiler efficiency itself—when burning as much as 1200 or 1400 pounds of coal per foot front of surface. At this efficiency we are able with oil to burn about the same weight or a trifle higher. The B.t.u. per foot front of furnace in that case would be much larger. With powdered coal we go a little beyond this, and I should say possibly 1800 to 2000 pounds per foot front of furnace is perhaps the maximum rate at which we can run for peaks, and 1200 to 1500 the rate at which we can get 80 per cent. efficiency out of our boiler on an all-day load. I do not think the end has come. I think we will go beyond this; but, if we do, we must line the furnace with something that will not slag and will not fall down when we get the average furnace temperature up to the point necessary in order to get in the boiler the higher absorption required for these high ratings.

G. E. Dignan: I am glad Mr. Orrok stressed the point that the boiler inclosures should be considered as part of the complete steam-generating unit, and I wish to stress further my point that operation, as far as the boiler inclosure is concerned, should be considered in the same light.

*Consulting Engineer, New York.

While most of the public utility plants have installed water walls and other types of construction with a decreasing use of refractories, the small industrial plants will continue to use refractory boiler inclosures and they can profit by the example shown by larger and more costly units.

R. E. Butler:* Mr. Dignan has brought out some very fine points in his paper. It is a very interesting subject and one which interests almost all of us who are engaged in power-plant work. One important thing mentioned in his paper is the question of uniformity in the size of brick. This has led a good many of our customers to whom we have sold boilers to use fire-brick throughout the wall instead of putting a fire-brick lining on the inside of the furnace setting. They have made the entire wall of fire-brick simply to be able to use a uniform brick throughout the walls. Of course this construction somewhat increases the cost of the brick, but they have found that the additional cost of the solid fire-brick wall is largely offset by the saving in labor due to using brick of uniform size. None of the red brick is of the same size as the fire-brick, and this difference in size requires a bit more labor in laying up the walls. Furthermore, a more stable wall, and one less apt to crack, results from using the fire-brick throughout.

One thing Mr. Dignan mentioned, which I do not think he brought out as well as he might, is the question of quality of fire-brick. This is of the greatest importance. There are on the market many kinds of fire-brick that are supposed to be first quality and are sold as first quality. In actual service, however, there is a very great difference in these various makes of brick.

The kind of brick often makes a tremendous difference in the life of the lining of the furnace. We very recently had this particularly called to our attention. A customer installed some of our boilers and built the furnace of a so-called first-quality brick which hardly lasted any time after the boiler was put in service. These brick were then replaced with another so-called first-quality brick, and the second lining lasted only a few weeks. Now he must entirely rebuild the furnace, using a third make of brick, which we hope in this case will

*Sales Engineer, Babcock & Wilcox Co., Pittsburgh.

really prove to be first quality. He would have saved quite a lot of money had he, in the first place, used a really first-quality brick.

G. E. Dignan: I certainly agree with Mr. Butler regarding uniformity of refractory shapes, and that is something we always try to get. The greatest care should be used in selecting refractory material, and the use of some of the higher-priced material can be justified under certain severe conditions that ordinary fire-brick will not withstand. However, I do not believe that the general use of the high-priced refractory material is justified and, as a matter of fact, we have no commercial refractory that will withstand the severe conditions in the boilers of large output. High-grade refractories go more slowly, but they are not sufficiently resistant to make them last over a period of years, and the increased cost of such refractories often makes the economical balance a matter of question.

CHARACTERISTICS OF CENTRIFUGAL FANS*

By T. G. Estep† and C. A. Carpenter‡

It is our purpose to present general information based on tests and manufacturers' data with the following objectives:

1. To show the existing relationships which limit the performance of a fan or blower of any given design.
2. To show the effects of some simple variation in this design.
3. To show the different operating characteristics of the more prevalent types of fan.
4. To show some of the effects of incorrect applications of fans.

If we consider a fan of specific design, certain general conclusions may be drawn based on the theory of similitude. Assume that a fan has been built and tested. Assume that the design has been carefully laid out to scale. Then by changing the scale of our drawings we can build an entirely different size fan of similar characteristics but very different specific performance.

Certain definite laws apply in a general way to fans of similar design for the same relative position regarding efficiency. They are as follows:

1. The speed is proportional to the square root of the head.
2. The power is proportional to the 3/2 power of the head.
3. The power varies as the square of the diameter of the impeller.
4. The speed is inversely proportional to the diameter.

From these laws, by simple algebra, a constant may be determined which definitely describes the relation between r.p.m., pressure in inches of water gage, and capacity in cubic feet per minute for fans of this one design. This constant is usually called "specific speed," and when the relation between fan efficiency and specific speed is plotted the result is a curve which describes quite fully this design of fan and is of great value in determining the limitations of any given design.

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†Associate Professor of Mechanical Engineering, Carnegie Institute of Technology, Pittsburgh.

‡Carpenter & Byrne, Pittsburgh.

Let N = Speed of fan in r.p.m.
P = Air horse-power.
D = Diameter of impeller.
H = Head.
H_1 = Unit of head = one inch water-gage.
P_u = Unit of power = one air horse-power.
N_1 = Speed of impeller at one inch head.
P_1 = Power of impeller at one inch head.
D_u = Diameter of a homologous impeller developing one air horse-power at one inch head.
K = A factor representing the speed of a similar impeller developing one horse-power at one inch head.
V = Cubic feet per minute.
C = A constant.

The four laws stated above are expressed algebraically as follows:

$$N_1 : N = \sqrt{H_1} : \sqrt{H} \qquad (1)$$

$$P_1 : P = (H_1)^{3/2} : (H)^{3/2} \qquad (2)$$

$$P_1 : P_u = (D)^2 : (D_u)^2 \qquad (3)$$

$$N_1 : K = D_u : D \qquad (4)$$

Rearranging these equations,

$$N_1 = N\sqrt{\frac{H_1}{H}} \qquad (1)$$

$$P_1 = P\left(\frac{H_1}{H}\right)^{3/2} \qquad (2)$$

$$D_u = D\sqrt{\frac{P_u}{P_1}} \qquad (3)$$

$$\frac{N_1}{K} = \frac{D_u}{D} \qquad (4)$$

Substituting equations (1), (2) and (3) in equation (4),

$$\frac{N\sqrt{\frac{H_1}{H}}}{K} = \frac{D\sqrt{\dfrac{P_u}{P\left(\frac{H_1}{H}\right)^{3/2}}}}{D} = \sqrt{\frac{P_u}{P\left(\frac{H_1}{H}\right)^{3/2}}}.$$

$$\text{Simplifying, } K = \frac{N\sqrt{P}\ (H_1)^{5/4}}{\sqrt{P_u}\ (H)^{5/4}}.$$

$$\text{If } P_u = 1 \text{ horse-power and } H_1 = 1 \text{ inch, } K = \frac{N\sqrt{P}}{(H)^{5/4}}.$$

$$P = \frac{V \times H}{C};\ K = \frac{N\sqrt{V}}{C\ (H)^{3/4}}.$$

$$K^1 = \frac{100\sqrt{V}}{C\ (H)^{3/4}}.$$

Taking r.p.m. at 100, giving a constant for 100 r.p.m. which we shall call K^1, we can plot relations between quantity in cubic feet per minute, head in inches of water, and K^1. On logarithmic paper these

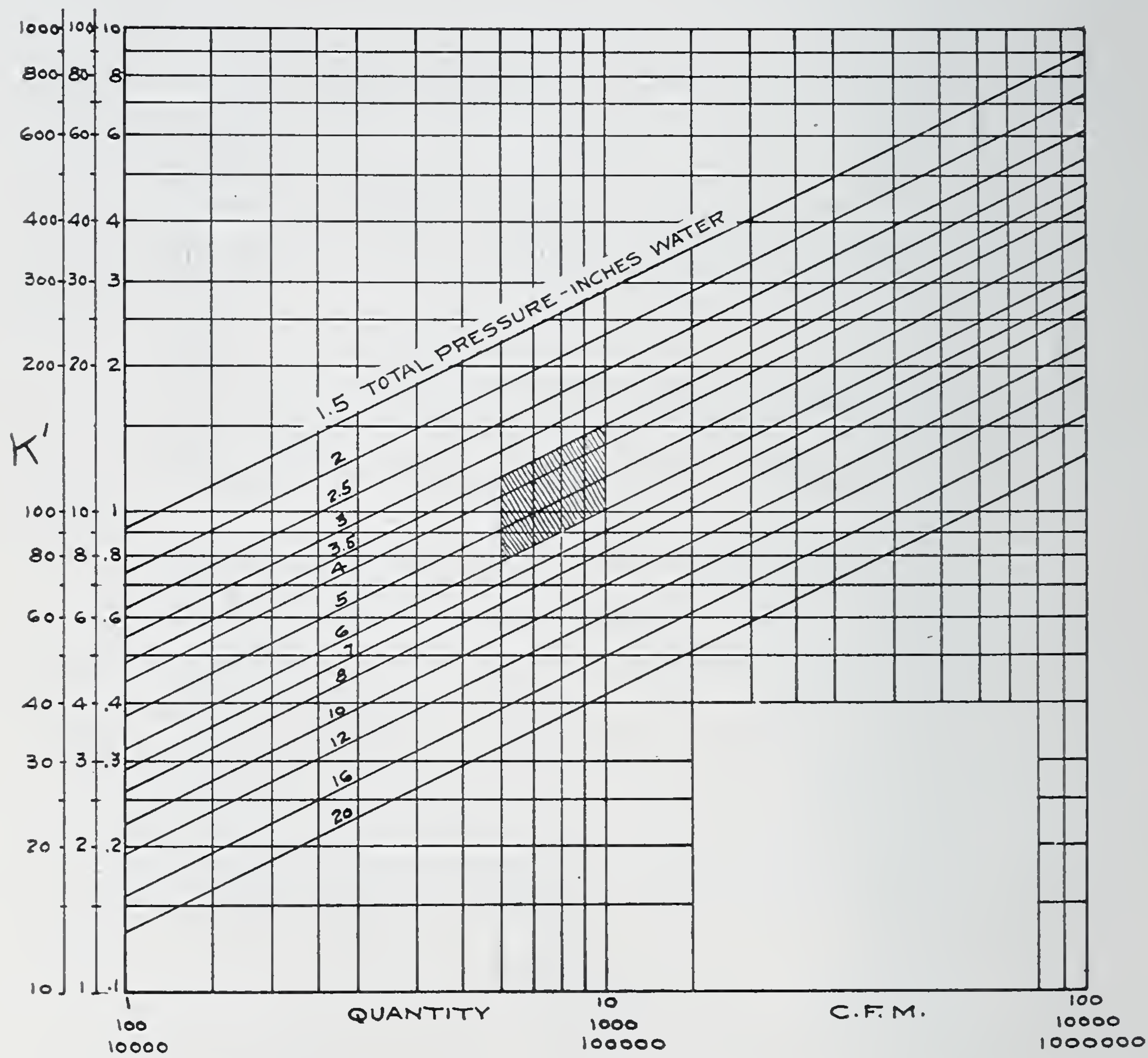

Fig. 1. Interrelation of Head, Quantity, and Specific Speed for 100 Revolutions per Minute.

relations plot as straight lines as shown in Fig. 1. By simple arithmetic, correcting for actual r.p.m. instead of our constant 100 r.p.m., we derive the actual specific speed required of the fan to be designed.

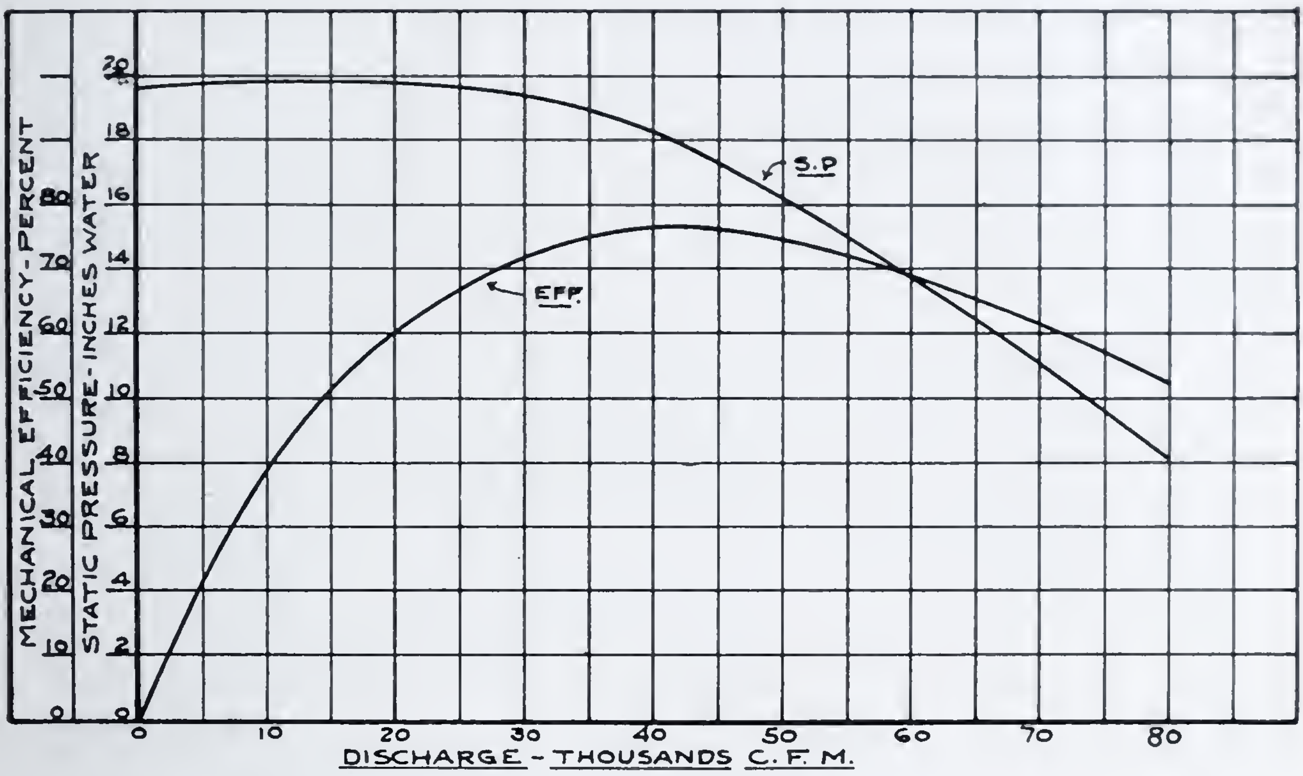

Fig. 2. Characteristics of Fans with Backward-Curved Blades.

The following figures show the application of the relation between efficiency and specific speed in determining the limitations in the application of any one fan design.

Fig. 2 shows the usual head-quantity and efficiency-quantity curves of a fan having backward-curved blades. Fig. 3 presents a curve for the relation between efficiency and specific speed.

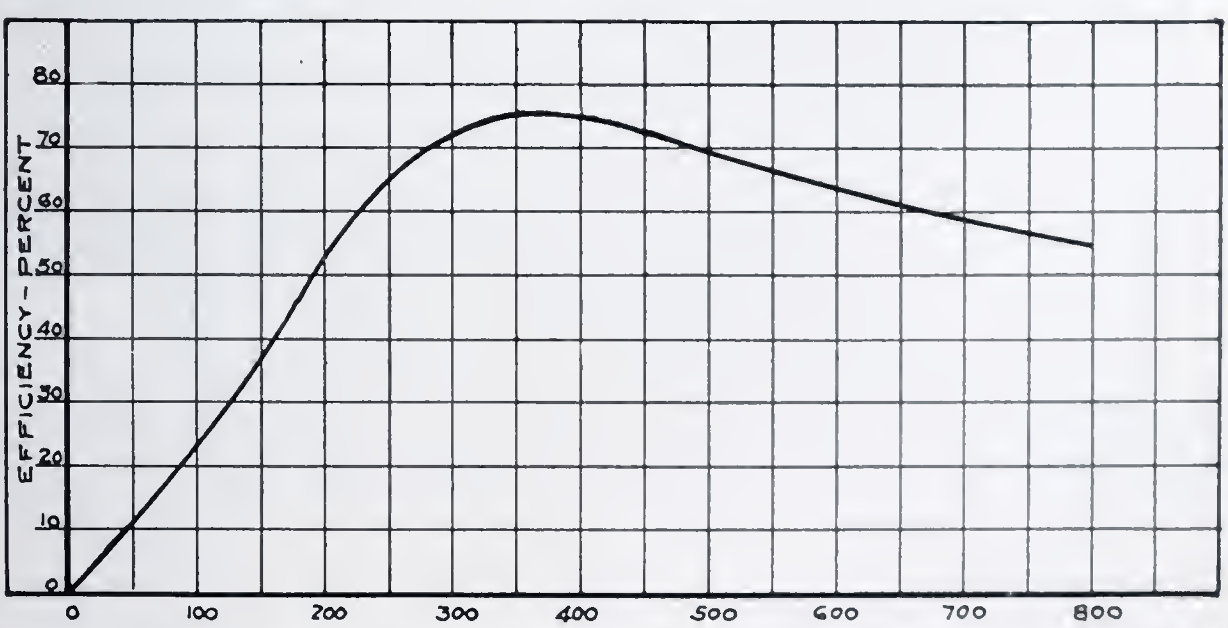

Fig. 3. Efficiency and Specific Speed of Fans with Backward-Curved Blades.

Suppose that it is required to build a fan to have a capacity of 75,000 cubic feet per minute at a constant speed of 1200 r.p.m. and develop a total pressure of 10 inches of water.

Substituting the above values in the equation for specific speed, and solving (or using the chart in Fig. 1), a value of 735 is obtained. Referring to the curve in Fig. 3, it is seen that this specific speed gives an efficiency of about 57 per cent. In other words, this design can not be used under the conditions stated without considerable sacrifice in efficiency.

Suppose, however, that a specific speed of 350 is chosen, which, from the curve, will give the highest efficiency possible. Again sub-

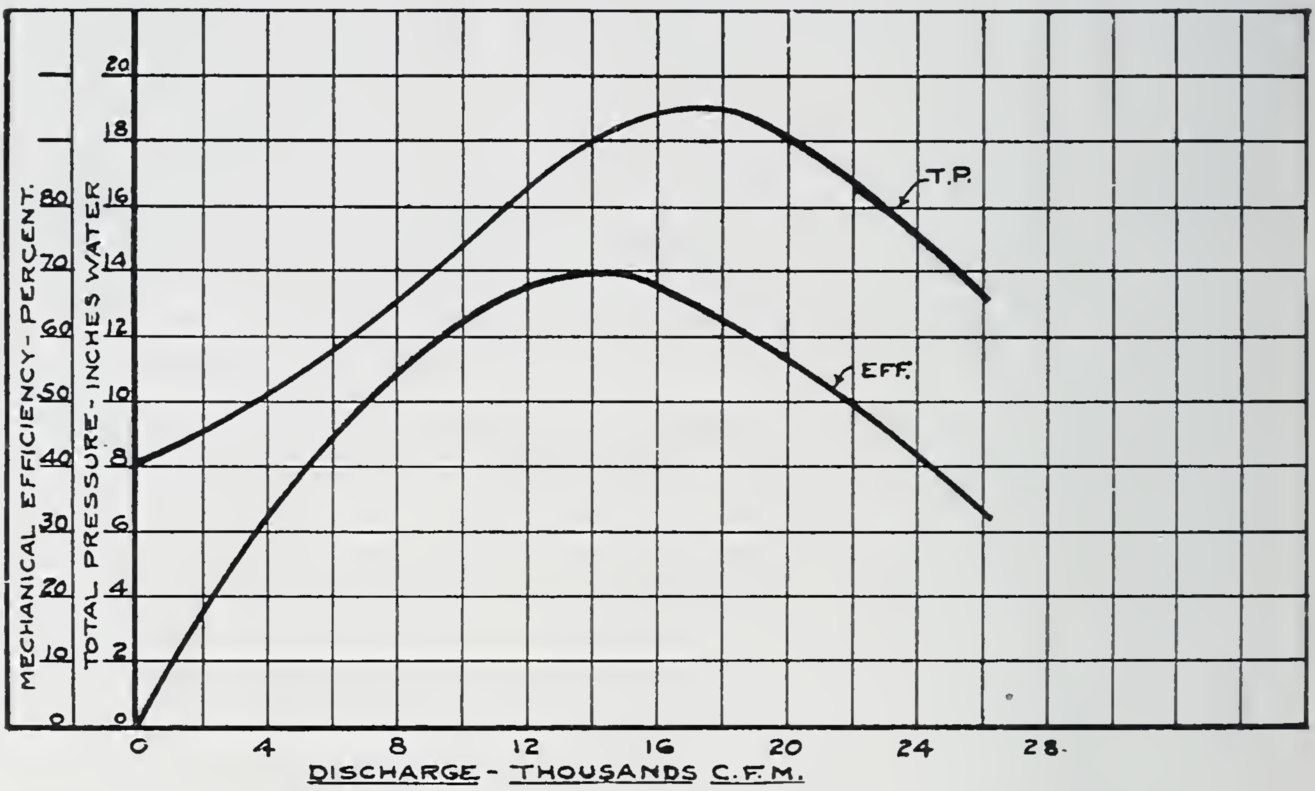

Fig. 4. Characteristics of Fans with Forward-Curved Blades.

stituting in the equation mentioned and solving for the actual speed, a value of 572 r.p.m. is obtained, which is the required speed of a homologous fan to give the best results under the conditions stated.

Fig. 4 and 5 show corresponding curves for a fan having forward-curved blades. It is to be noted that fans of this type have a very much narrower range of specific speed for good efficiency than those having backward-curved blades. The dotted vertical lines on the specific-speed curves show the limits within which the manufacturer offers this design of fan.

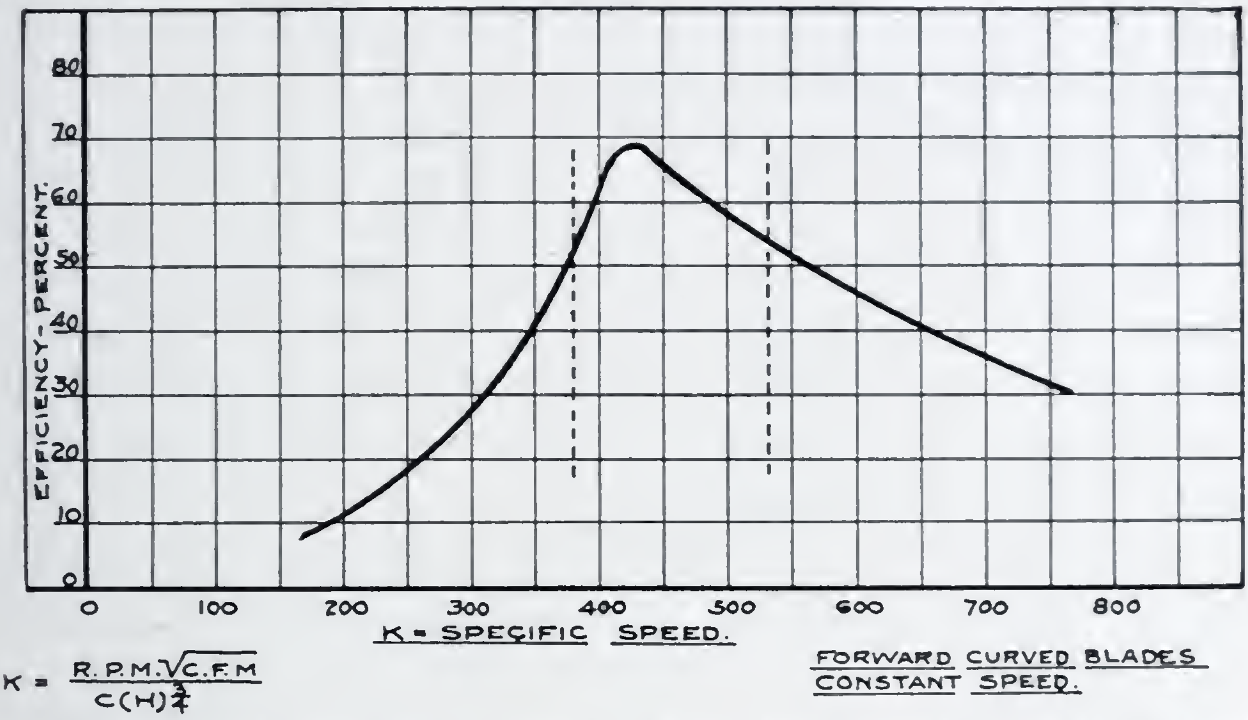

Fig. 5. Efficiency and Specific Speed of Fans with Forward-Curved Blades.

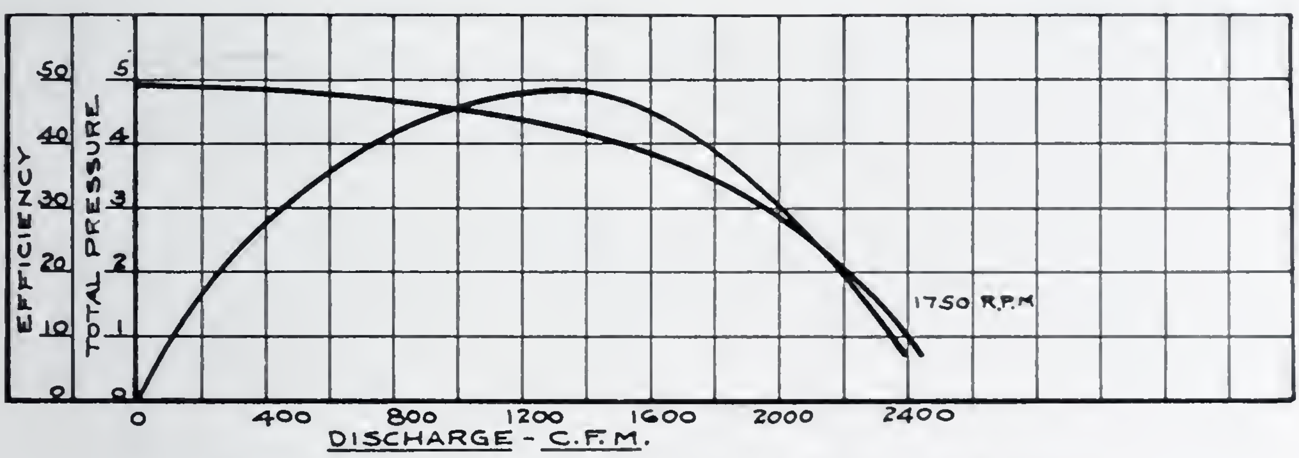

Fig. 6. Characteristics of Fans with Radial Blades.

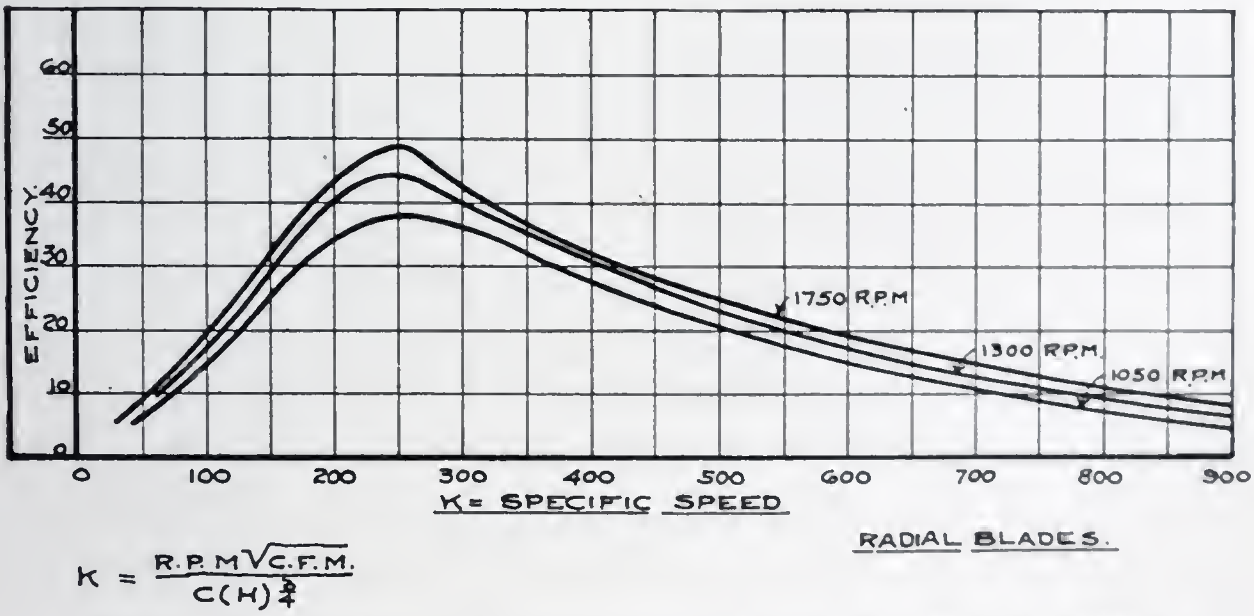

Fig. 7. Efficiency and Specific Speed of Fans with Radial Blades.

Fig. 6 and 7 are interesting because they show clearly the soundness of the theory of specific speed and its application. These curves are plotted from carefully made tests on a variable-speed, radial-bladed, steel-blade fan. For the purpose of the chart, only three speeds have been plotted, but they show clearly that no matter what rotative speed is used, the best efficiency will obtain at a fixed specific speed. It should also be noted from this chart that not all fans of homologous design will have the same maximum efficiency, but that the best efficiency under given conditions of speed, capacity, and head will be obtained with a fixed specific speed.

The authors believe that the relation of homologous fans between efficiency and specific speed shows the limitations in design better than any other method so far proposed, and this principle deserves a wider application. Fortunately, the fan designer has several ways to escape these limitations. The simplest variation in design is to change the width of wheel. Within broad practical considerations, the width of a fan wheel of the multi-vane type may be varied considerably without much sacrifice in efficiency. Of course, an absurdly narrow or wide wheel becomes inefficient.

If careful tests were made on a fan of given design with varying width of wheel and the relations between efficiency and specific speed were plotted, it would show at once the limits in the ratio between wheel width and diameter for the best efficiency, and the designer would be able to decide at once whether or not the required conditions could be met by varying the width of the wheel.

If this expedient fails, more radical changes in design become necessary, and we must consider the various types of fan available. In popular terms, fans of the multivane type may be forward curved, radial bladed, or backward curved. Many variations in operating results may be obtained by different choices of fans. Buyers of fans therefore should analyze their air requirements carefully so that when asking for bids they will obtain prices on equipment of proper characteristics. Merely to ask for quantity, pressure, and an approximate speed in no way fixes the type of fan. Such a specification simply insures a quantity-perssure relation thoroughly limited in character with respect to any particular fan, even under variable-speed conditions.

It is interesting to note in this connection that a given airway, such as a ventilating duct, fixes a definite relation between quantity of air and pressure required to permit flow. This relation may be expressed by the formula $Q^2 = ch$, in which Q = cubic feet per minute, h = total head in inches water-gage, and c = a constant. Within the usual working range of a fan at variable speed, approximately constant efficiency will follow an exactly similar relation, $Q^2 = ch$.

It follows therefore that for a constant fixed airway not subject to any material changes in size, length, coefficient of friction, etc., a fan of any design as regards shape of blade would give satisfactory results. The choice would be determined by price, efficiency, and construction. This statement is made with the understanding that the requirements are accurately determined and the fans offered would meet their guarantees—conditions not always true in practice. By far the greater number of fans are bought to meet requirements that may vary from time to time, and with a very considerable doubt as to the correct quantity-pressure relation. It is unnecessary to dwell on this statement, as all of us are familiar with the difficulties involved in getting exact air requirements.

In considering fans to meet a variable situation, with the probability that the actual requirements will differ from those suggested in the inquiry, a study of characteristics becomes important. The buyer in this case really wants equipment that will do reasonably well in a whole zone of operating conditions indicated by the shaded area on the diagram of Fig. 1. If the limits of this zone are closely approximated it is possible to select the design that will best meet the requirements.

Another factor determining fan design is the effect of products which are passed through the fan. This factor, of course, is purely practical. If special passageways are necessary in a fan wheel to prevent unbalancing, excessive wear, or other mechanical troubles, the question of fan theory becomes secondary and the fan manufacturer must bend his energies to meeting the mechanical problem as best he may.

It would be well to consider briefly what difference it makes if fans be bought regardless of characteristics, as long as they seem amply big for the job. The following diagrams show some of the common errors in selection or application of fans.

Fig. 8 relates to a fan with forward-curved blades, and Fig. 9 to a fan with backward-curved blades. In each case the fan is up to specifications, but the pressure actually required is higher or lower than estimated.

In Fig. 10 the fan is too large for the job.

In Fig. 11 the speed of the fan is too low, but fixed by constant-speed, alternating-current motor.

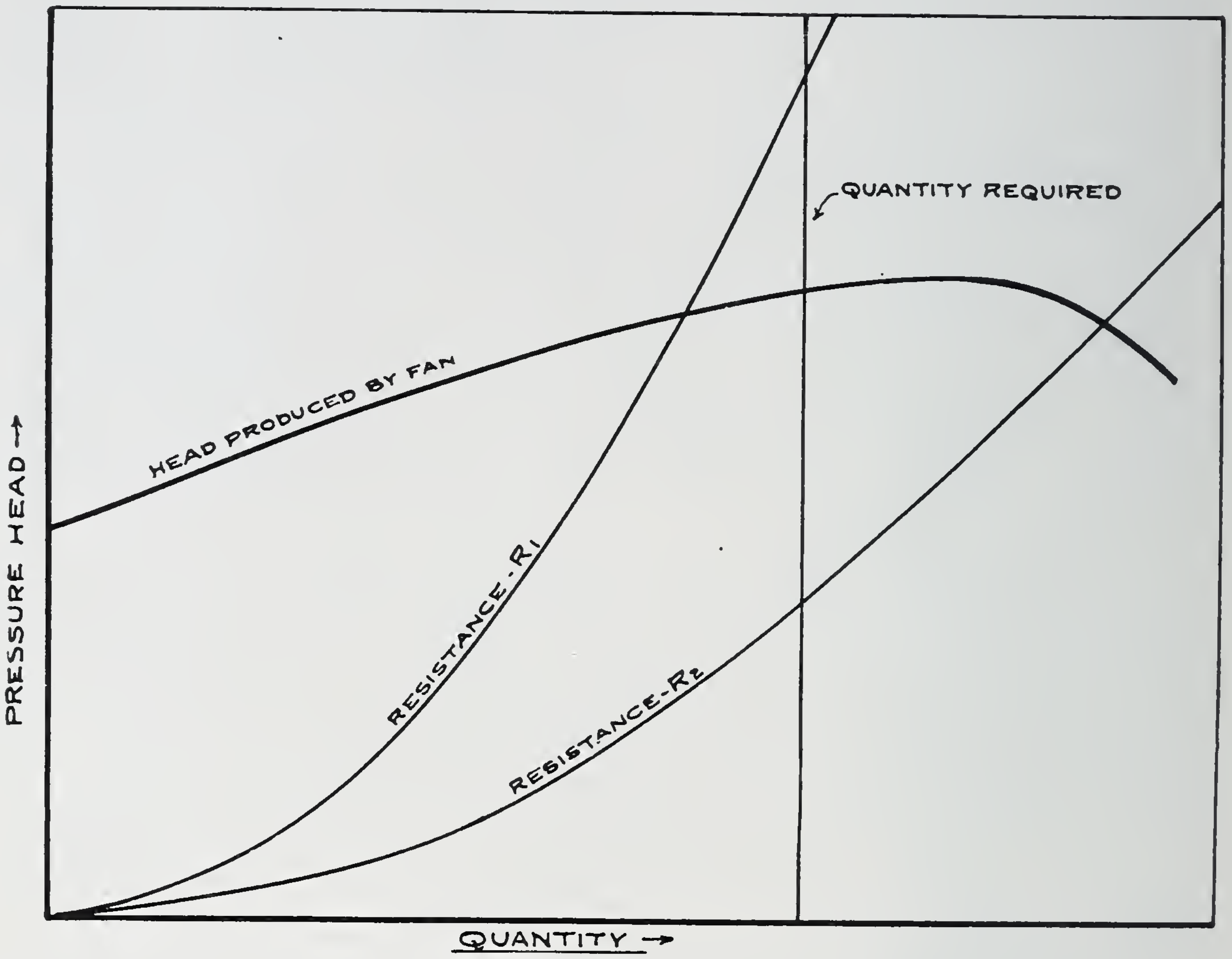

Fig. 8. Fan with Forward-Curved Blades. Air-Duct of Incorrect Size.

It should be noted that to correct the errors shown above, radical and probably costly changes are necessary. This again emphasizes the necessity of estimating the requirements very closely before the installation is made. A given fan has fixed characteristics, and if the requirements do not conform to these characteristics a bad installation will result. Fans of different design have distinctive characteristics, and this should be kept in mind in drawing up specifications. The fan designer works within fixed limits and can not offer a fan of a chosen design to meet the whole range of capacity, pressure, and speed. He

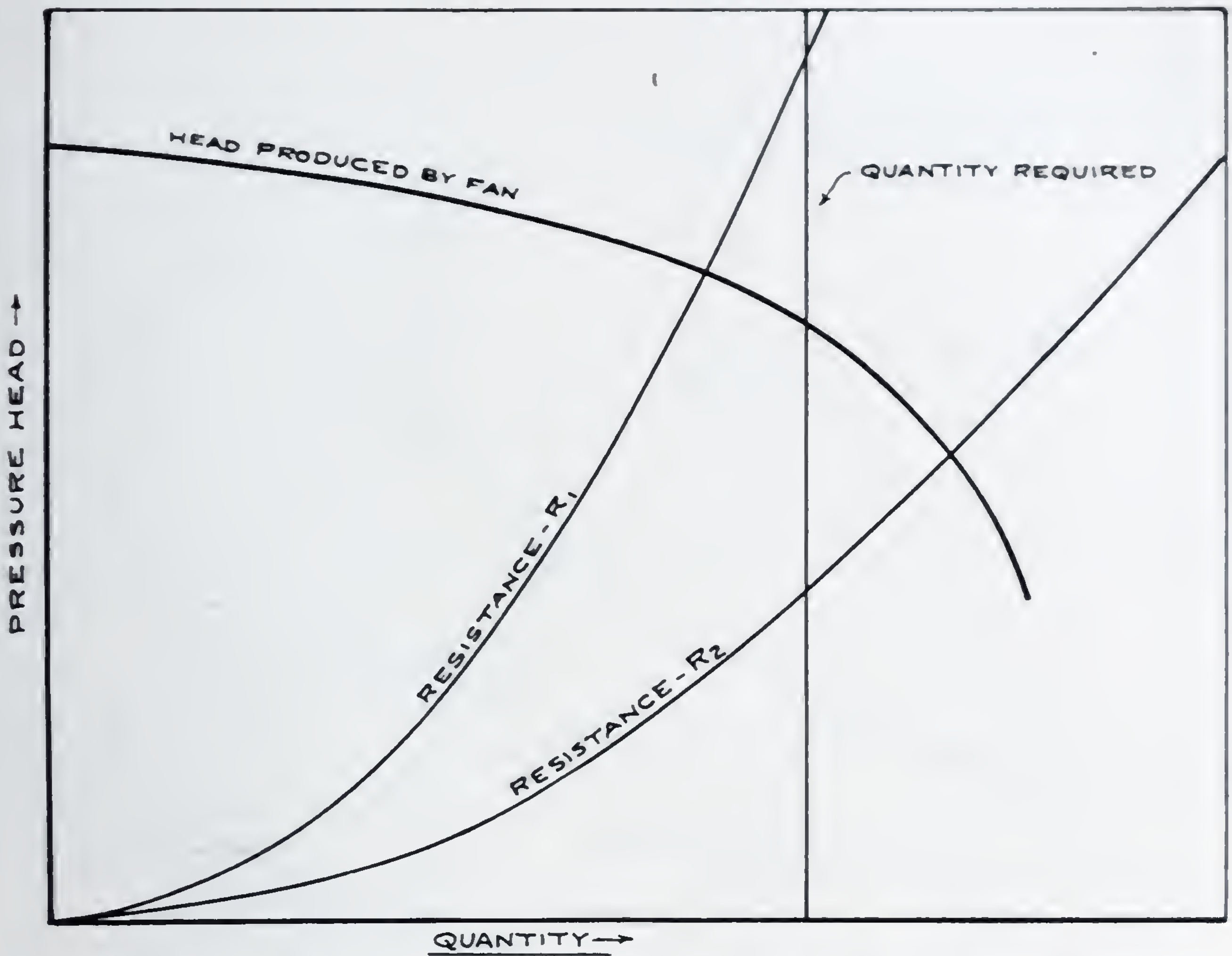

Fig. 9. Fan with Backward-Curved Blades. Air-Duct of Incorrect Size.

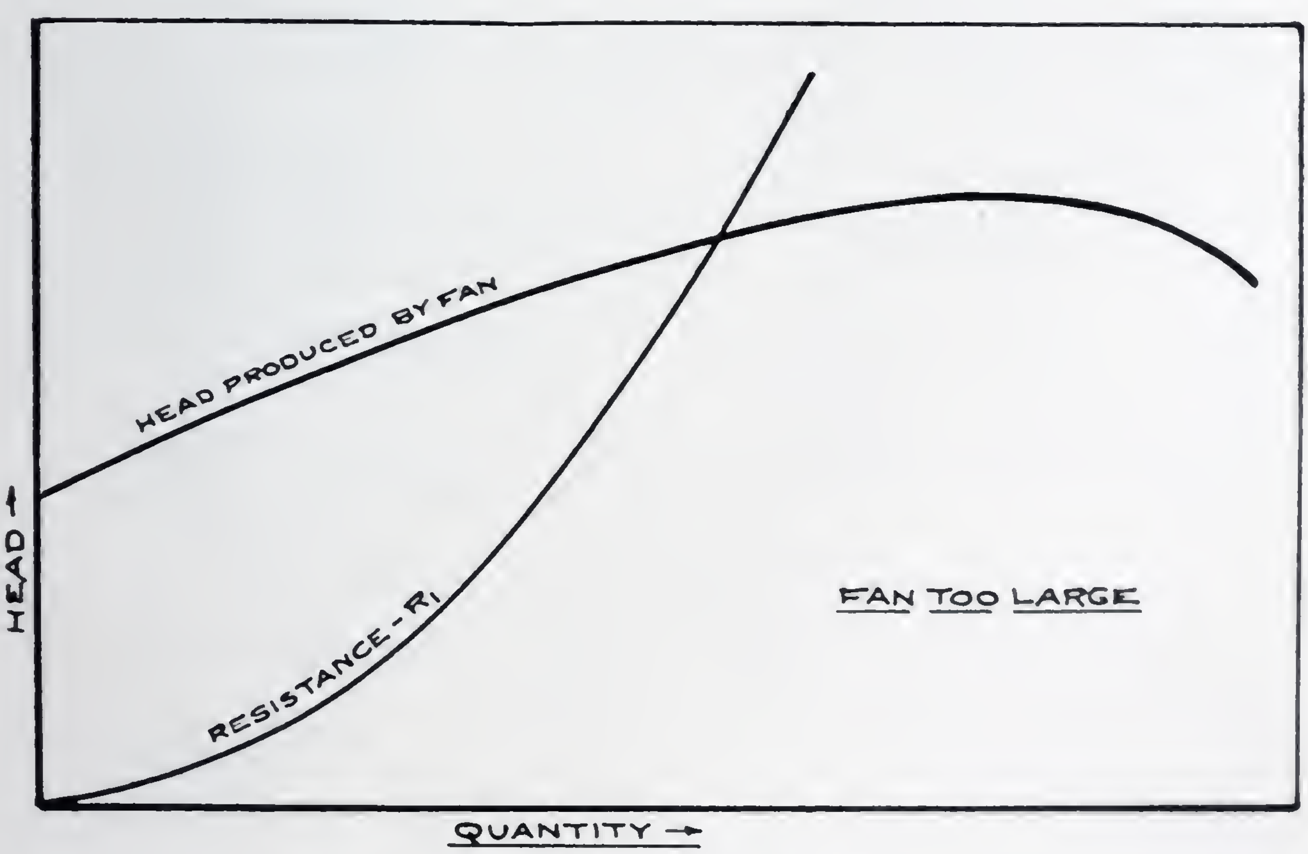

Fig. 10. Fan Too Large.

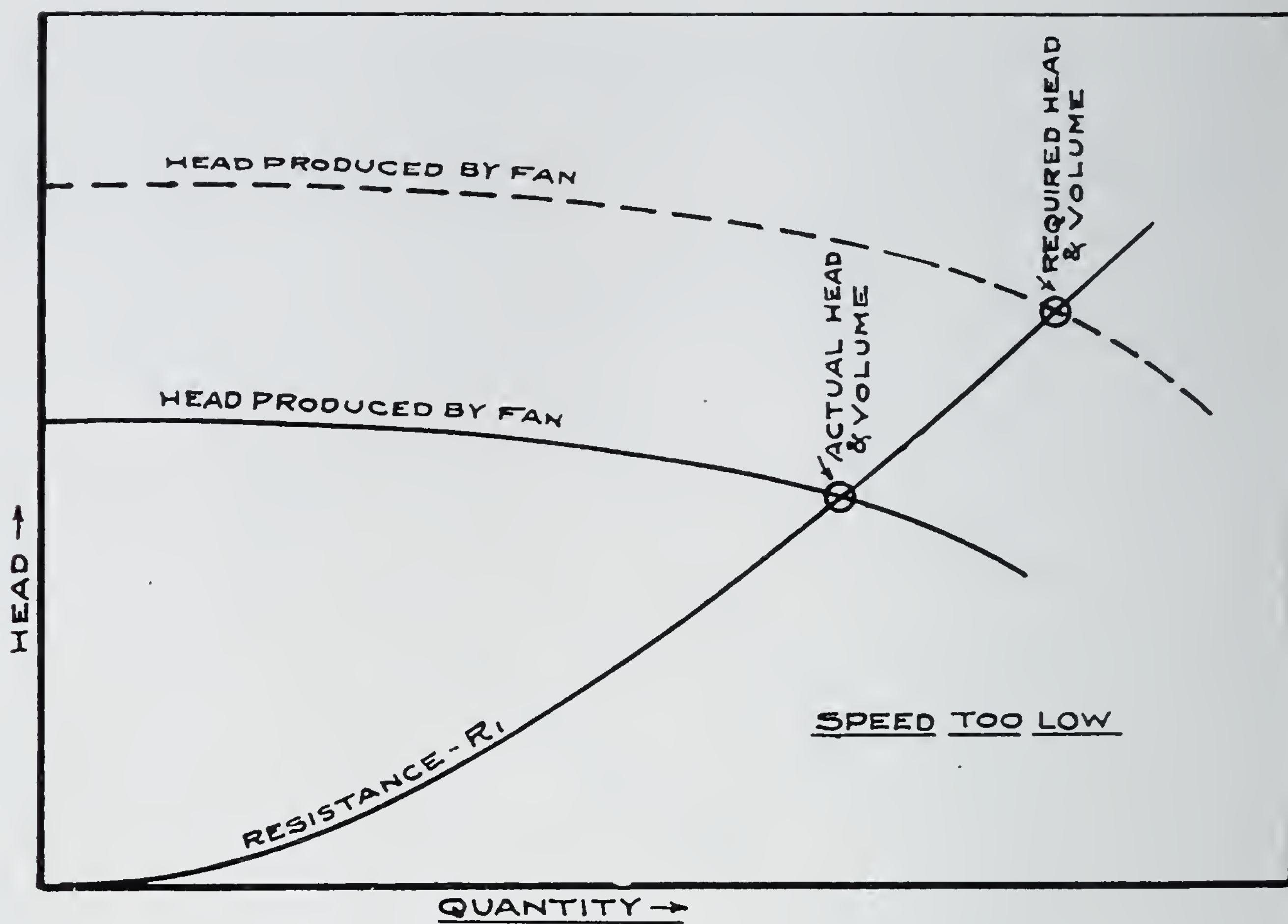

Fig. 11. Speed Too Low.

must conform to the limits imposed by his design and the buyer ultimately must recognize this.

One other point should be mentioned before closing. There appears to be considerable misuse of the term "static pressure." Considering a given fan application, no flow can take place without velocity. Likewise, no fan can deliver any air from its outlet unless there is velocity. Furthermore, conversion from static to velocity head, or vice versa, occurs when the cross-section dimensions of airways are changed. The efficiency of this transfer depends upon the manner in which the airway dimensions are varied. It follows that a final velocity head must remain in the airways when air is flowing, and that the fan must produce this velocity head. The logical way to meet this situation is by estimating the residual velocity and the static pressure required to overcome friction losses. With due consideration of the local situation determining how the connection between the fan outlet and the airways may be worked out, it becomes possible to select a fan with the right static head and velocity head to meet requirements. Reference to static pressure alone does not take in the whole story.

DISCUSSION

George A. Orrok:* I am very glad to have heard the paper on fans, in which the authors have applied the ordinary principles of hydraulics that we all use in the design of water-wheels, steam-turbines, and centrifugal pumps. This has not previously been done

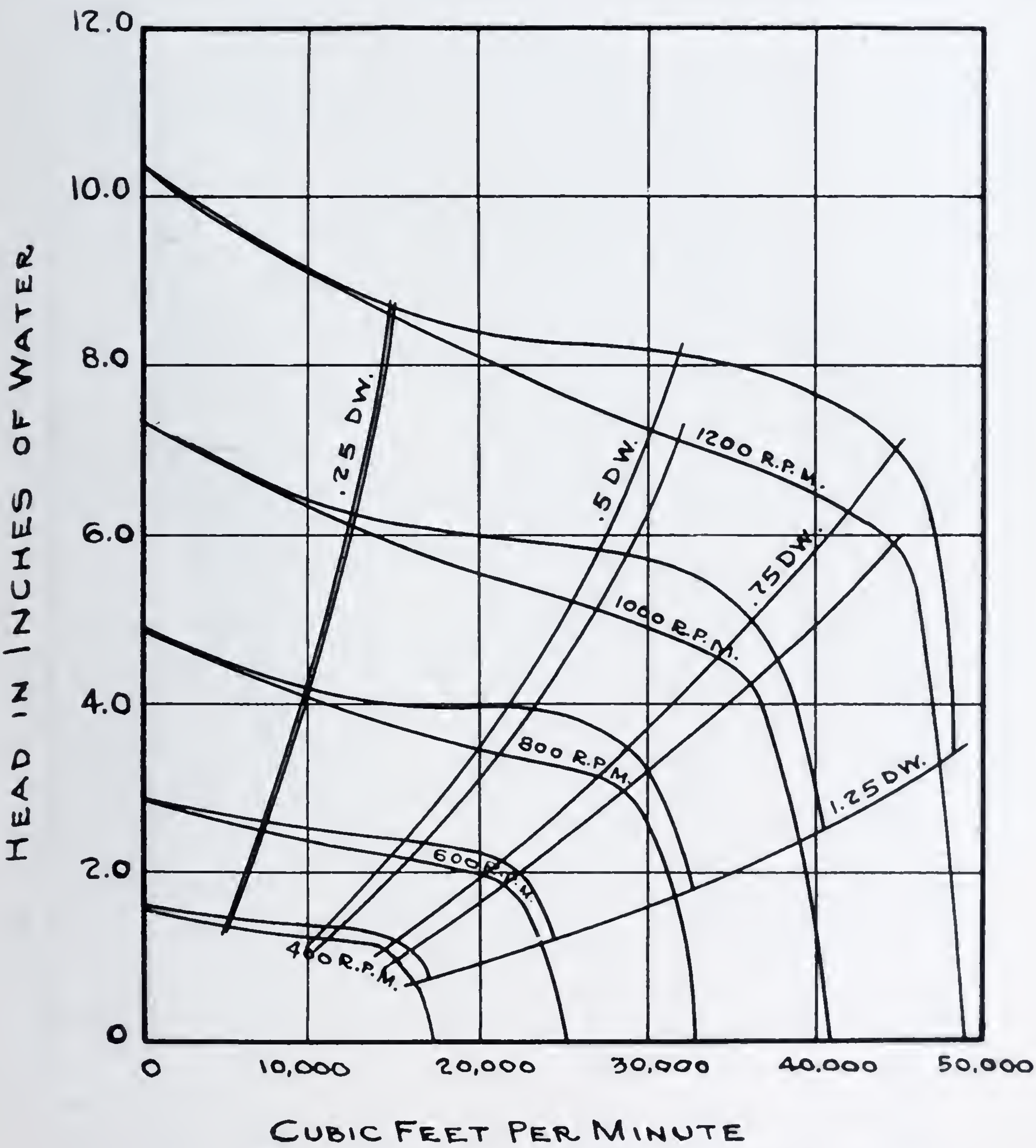

Fig. 12. Characteristics of Fans with Forward-Tipped Vanes.

to any great extent, and it is a very good way of checking up design or deciding on various characteristics of design. Personally, I like a different diagram when I have a certain problem under considera-

*Consulting Engineer, New York.

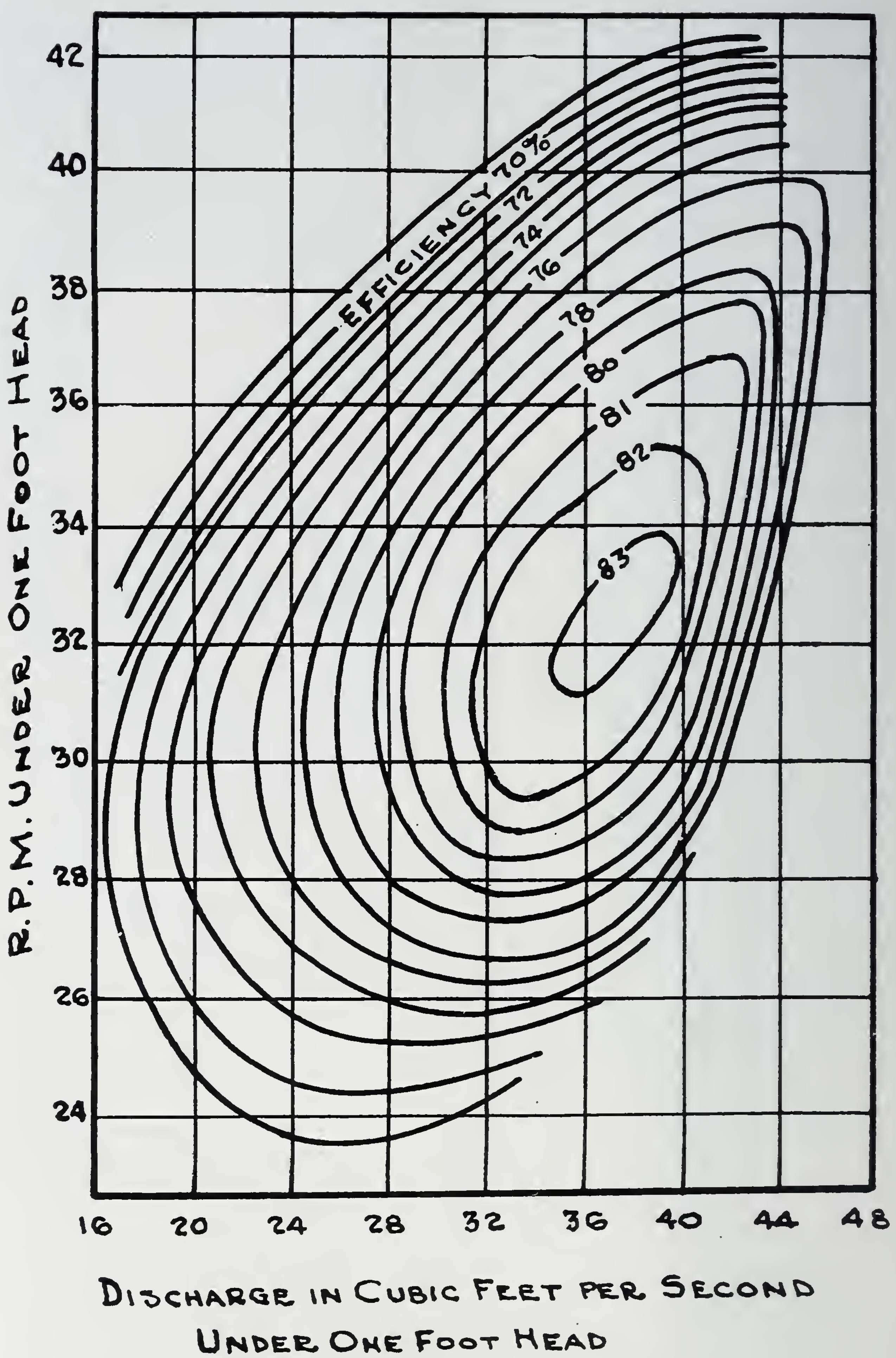

Fig. 13. Curves Indicating Various Efficiencies.

tion. The authors have come pretty close to using the diagram which I personally prefer, and which I always use when I make a test on a certain size of fan.

They show a diagram with quantity of air delivered as abscissæ and with the head in inches of water, or feet of air, or any other unit as ordinates; and they show three diagrams, one for fans with backward-sloped blades, one for fans with radial blades, and one for fans with blades tipped forward. The forward type characteristics do not quite agree with certain fans—a great many in fact with forward-tipped blades, which I have tested myself. I get a characteristic like that shown in Fig. 12. This is a characteristic of a fan with forward-tipping blades. I usually add the radial curves indicating openings.

It would be interesting, and I have never seen it done, to plot the field as we do in water-turbine tests, using discharge under one foot head as abscissæ and r.p.m. under one foot head as ordinates and get a field in which efficiencies are shown in a family of curves as in Fig. 13. We do that for centrifugal pumps and for turbines, and the same thing could be applied to fans, because they are all hydraulic apparatus and they follow the same laws.

E. B. Plapp:* I noticed that the formulæ given in the paper check very closely with the hydraulic formulæ for centrifugal pumps. This brought to my mind the question as to how far these formulæ are exact when used for air. Mention was made of the fact that fans are almost getting to be air compressors these days. That, of course, brings in the question of the effect of the compressibility of air. Mention was also made of the effect of the air temperature in figuring fan capacities. In this case, also, the effect of the change of density of the gas from standard conditions must be considered. Since the hydraulic formulæ are based on water, which is not compressible, I am curious to know how far the formulæ given in the paper can be applied to air problems.

In stoker work we make a correction for altitude. I would like to know what allowances are made for altitude by fan manufacturers.

In stoker operation the matter of parallel operation of fans is important. In general, fans having a drooping characteristic throughout their range of operation will operate satisfactorily in parallel. In

*Sales Engineer, Combustion Engineering Corporation, Pittsburgh.

this connection I like to compare a fan with a direct-current generator. Shunt generators, having voltage characteristics like the pressure characteristics of fans with which the static pressure drops as the volume delivered increases, operate readily in parallel, as do the fans. Compound generators, on the other hand, where voltage rises with the load, compare with fans having forward-curved blades and rising pressure characteristics, both often being troublesome to operate due to the tendency of one unit to "hog" all the load.

I have been very much interested in this method of applying a mathematical analysis. It gives one a guide to keep in mind when comparing characteristics of fans.

H. H. Downes:* In your forward-tipped curve is it not true that you often get a dynamic head in a fan which is higher than that pressure corresponding to the peripheral speed of the wheel?

As to the fan with the forward-tipped blade, some people have the idea that it can not be used on certain classes of work, such as forced draft, due to the fact that through a certain range its pressure falls off with the capacity, which is not true with the fan with backward-curved blades. As a matter of fact, either can be used. There is no difference between the two types if they are properly selected. If this is done, the type with forward-curved blades never operates on that portion of the curves where pressure and capacity decrease together, but operates on a rising pressure the same as the backward-curved type. The only point to discuss between the two types of fans is what speed is desired. This alone determines which type should be used. Radial or straight-blade fans, as well as the backward curved, have a similar pressure curve, all of which are very different from the forward-tipped fan, yet similar when compared to that portion or range of the forward-tipped fan, through which it should operate, and will operate if properly selected.

The only fan that has 100 per cent. static and dynamic head at no delivery is a straight or radial-blade fan. Even the backward-curve fan rises a little from the static, no delivery, and in pressure blowers which have a slight backward tip of the blade the static pressure rises, and the dynamic very much so, above the static, no delivery.

*District Manager, American Blower Co., Pittsburgh.

F. M. Van Deventer:* The authors have presented the relation between efficiency and specific speed, which is a convenient tool for the designer, and might be helpful to the engineer who uses fans, if it were available. Manufacturers, however, have not in the past published this relation for their product. It is the intention of this discussion to show some of the pertinent aspects of the problem which confronts the plant designer, and some facts which may assist him in making the proper fan selection.

Generally speaking, the selection of a fan for forced or induced draft service becomes a compromise. This results from the fact that

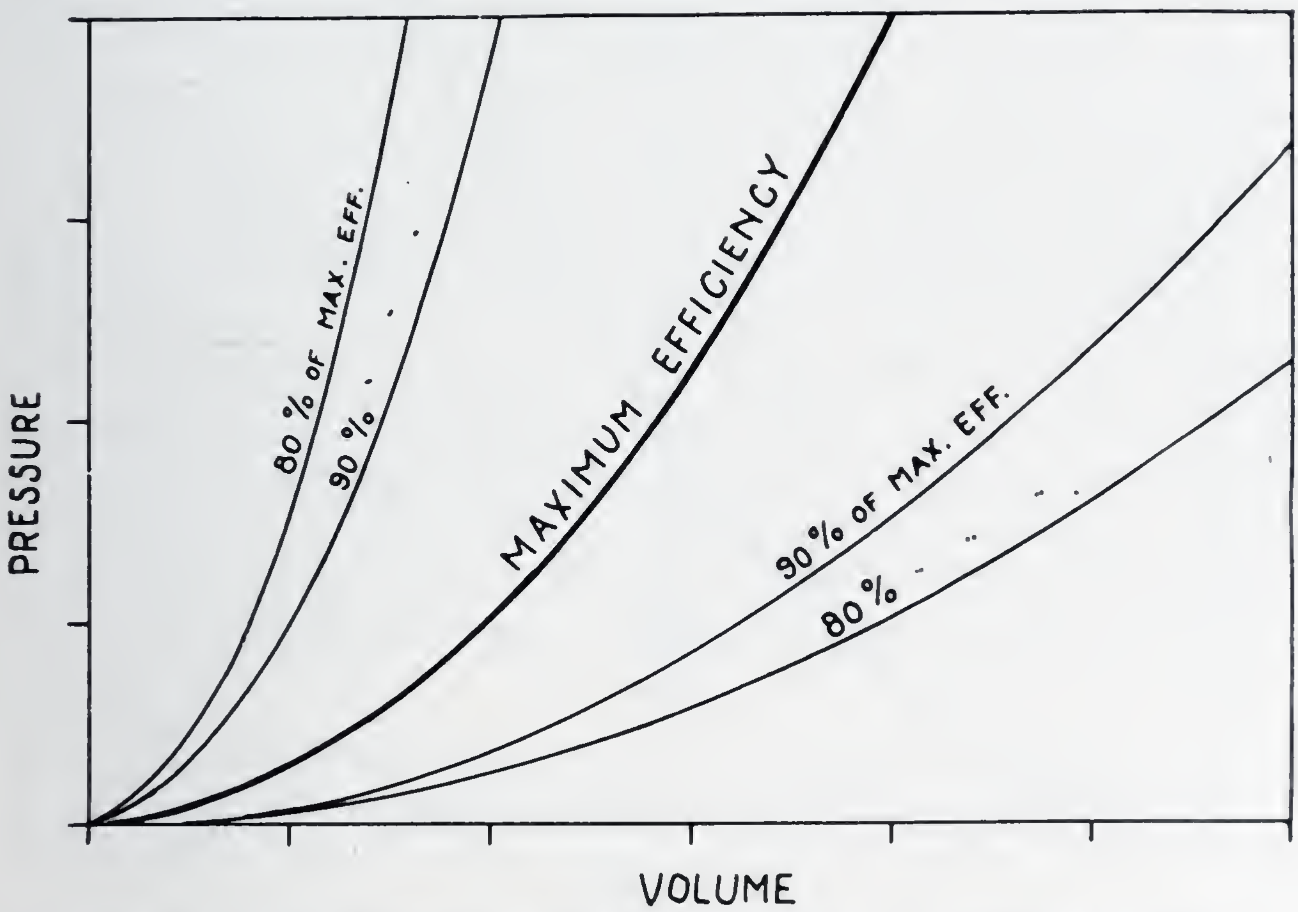

Fig. 14. Relation between Head and Volume for Constant Efficiency.

a certain maximum capacity is desired which requires the movement of a specific volume of air or gas against a specific head, and very often the maximum speed available for the maximum condition is dictated by the power characteristics, especially if alternating current is used. Normal operation, however, requires the movement of a smaller volume against a lower head. High fan efficiency at this point is essential for obvious reasons. While operation at the maximum condition is the exception rather than the rule, high fan efficiency at that point

*Construction Department, H. L. Doherty Co., New York.

also is desirable, since excessive power consumption by auxiliary equipment coincident with the plant peak-load deprives the station of an equivalent amount of available capacity.

It is pertinent to compare the inherent efficiency characteristic of a fan with the characteristic resistance of air and gas circuits. One of the most important fan characteristics is the relation between head and volume for constant efficiency. The authors expressed this relation by the formula $Q^2 = ch$. The writer prefers to state this proposition as applying to any specific fan thus: "For constant fan efficiency, the head varies as the square of the volume." This relation is shown

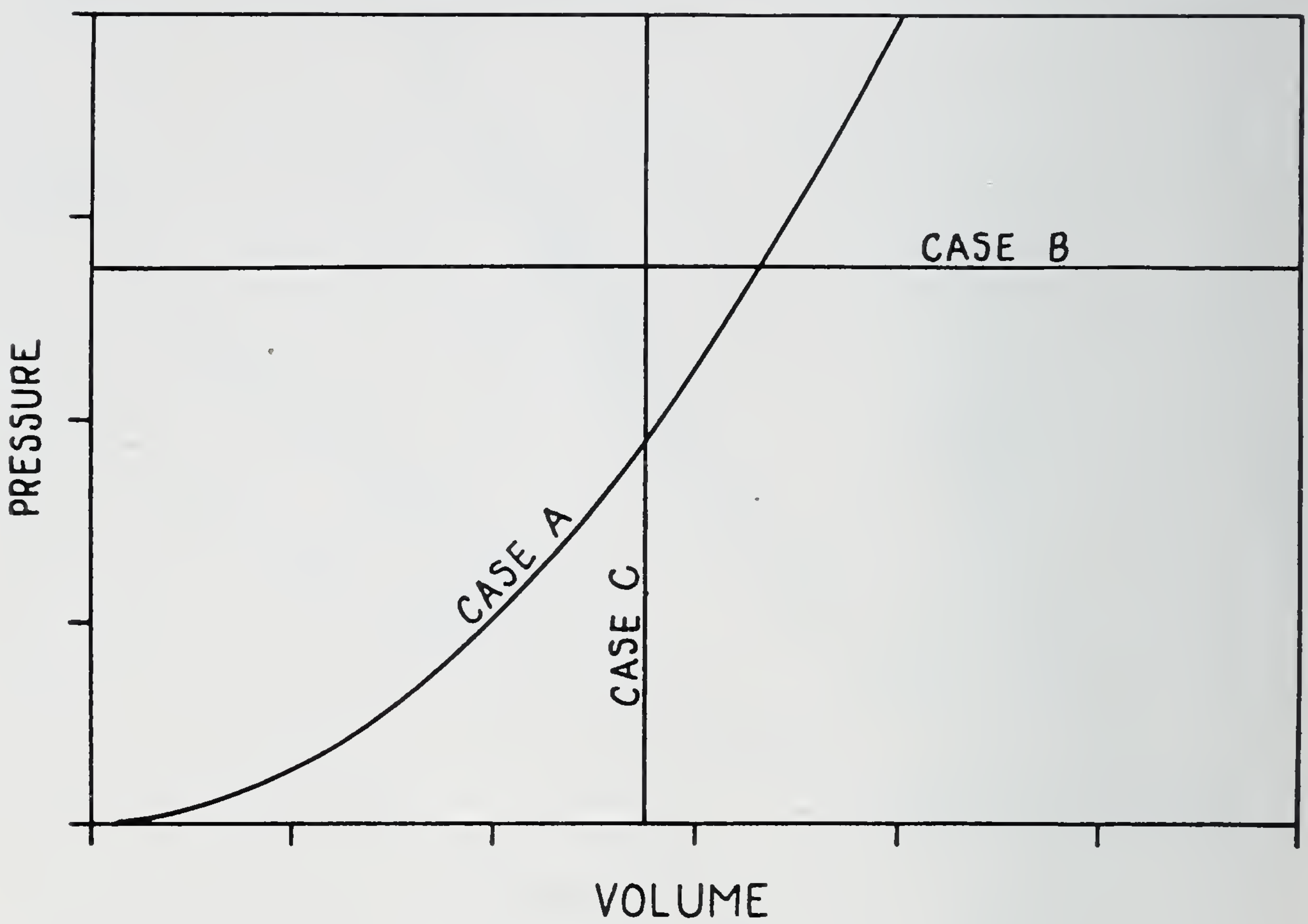

Fig. 15. Various Conditions of Fan Discharge.

graphically in Fig. 14. Here each constant-efficiency line is a second-degree parabola in which the head varies as the square of the volume. The heavy line is the locus of the pressure-volume co-ordinates at 100 per cent. of maximum efficiency, and the other lines similarly describe the relation between pressure and volume for several other values of constant efficiency.

From the foregoing it may be seen that if the pressure-volume relation for the resistance against which the fan is to discharge is that of a second-degree parabola, as shown in curve A, Fig. 15, it is osten-

sibly a simple matter to select a fan which will have maximum efficiency under conditions represented by any one set of co-ordinates on this curve. It would then follow that maximum efficiency would also result when operating at any other capacity from zero to maximum as long as the second power relation between pressure and volume exists. Of course, a standard fan size would be selected, and it might be necessary to accept a fan of which the static efficiency for the specific requirements would be, say, 62 per cent. instead of the maximum for that design, which might be 65 per cent.; but the efficiency would be constant throughout the range, be it 62 or 65 per cent. or some other value. Again, the limitation of speed might be a factor and require that a further sacrifice in efficiency be made.

Referring to Fig. 15, suppose it be necessary to discharge a varying volume of air against a fixed resistance, as represented by Case B, or a fixed volume against a variable head, as in Case C. For either of these cases it is possible to select a fan with maximum efficiency at some one point on the characteristic, but it is utterly impossible, at least with ordinary fan design, to obtain maximum efficiency at any other point on the characteristic curve. This is more apparent by assuming Fig. 14 superimposed on Fig. 15. The maximum-efficiency parabola may be made to cut any point on curves B or C by properly selecting the specific fan, but either curve B or C would intersect the lines of 90 per cent. and 80 per cent. of maximum efficiency, etc., at other points.

While cases similar to B and C are sometimes met in practice it is fortunate that they are the exception rather than the rule, and that most cases do follow the second-degree parabola relation. Ventilating systems which consist mostly of ducts and registers obey this rule closely. Ducts used in forced and induced draft systems may safely be assumed to obey this relation. Analysis of the draft-loss characteristics of several types of boilers and economizers indicates that the parabolic exponent varies over a considerable range, at least from 1.8 to 2.6, depending upon the spacing of tubes, arrangement of baffles, and direction of flow of gases with relation to the tubes. For superheaters, the exponent is in the nature of 1.7. For air preheaters, both plate and tubular, the exponent is most commonly found in the range from 2 to 2.3. It would be natural to assume that underfeed stokers would follow similar laws, and the tuyere orifices undoubtedly do.

but the combination of stoker and fuel bed does not. The real characteristic is virtually a straight line, the pressure varying almost directly with the volume of air. For comparison with the characteristics of other equipment,, such a line could be described as a parabola with the exponent unity. The probable explanation of this pecularity on the part of the stoker is that, on high loads, the overfeed and extension grates, and possibly part of the ash-pit, are supplied with an increasing proportion of air, either by the manipulation of dampers or by deeper penetration of the fuel bed by virtue of high wind-box pressure and greater resistance in the underfeed section. The net effect is equivalent to increasing the effective fuel-bed area and a slower pressure increase with increasing volume than would result from the more usual forms of resistance. In a typical forced-draft set-up embodying a fan, duct, air preheater, and more duct and stoker or secondary air ports if using pulverized fuel, the pressure-volume characteristic imposed upon the fan is a combination (by summation) of a comparatively flat curve and several parabolic functions. The resulting relation will usually not be a second-degree parabola, and, consequently, fan efficiency must be sacrificed at most points on the curve.

Analysis of a set of recently conducted tests indicates that the forced draft characteristic was a parabola with the exponent 1.3 at the higher ratings, flattening out to approximately 1 at the lower ratings. The induced-draft characteristic had an exponent of 2.2 throughout the major portion of the load range. The air circuit comprised a plate-type air preheater, an underfeed stoker, and an extensive system of ducts. The induced-draft circuit comprised boiler, integral economizer, air preheater, and ducts.

In most cases, several sizes of fans will attain the maximum requirement and will give reasonably good efficiency in the normal operating range. Price would favor the smaller sizes, but the speed required for the maximum condition would probably eliminate the smaller sizes on account of alternating-current characteristics.

For the remaining fans the problem is one of economics, and of the several methods which may be used, the following is an example. For each fan a composite figure is obtained consisting of four component items—(1) cost of fan, (2) capitalized cost of fuel required to operate the fan at the average load condition for a hypothetical year

at an assumed capacity use factor, (3) cost of motor required to drive the fan at maximum capacity and at corresponding pressure and efficiency, (4) (optional) if the plant will be called upon at times to deliver every possible kilowatt of output that can be developed, another figure should be added to represent the value of plant capacity required to operate the fan at maximum rating. The net value (per kilowatt) of this capacity is not the unit cost of the complete plant, but rather the unit cost of additional turbine, boiler, and auxiliaries with housings. This figure should be in the neighborhood of $60 to $70, instead of $100 to $150, the latter representing the range of total initial plant cost, including real estate, design, etc.

With such a study for each fan completed, it is obvious that the one with the minimum composite cost constitutes the proper selection. This will not always be the fan which has maximum efficiency at the normal point of operation, but will be the one with the proper economic balance between efficiency and investment.

The authors refer to the prevalent misuse or misunderstanding of the term "static pressure," but their recommendation also is misleading, as is the ordinate called "mechanical efficiency" in Fig. 2. The writer believes this should be "static efficiency."

The authors refer to the fact that the fan must produce velocity head in addition to static pressure, and it is to be inferred from their subsequent statements that they recommend adding the residual velocity head to the static head required to overcome friction, etc., in order to determine the total head on the fan.

Truly, the fan must produce the velocity head, but all common fan tables and charts are based upon static pressure at the discharge flange, and this static pressure is the residual pressure after some of the total head has been consumed in creating the velocity corresponding to the tabular flow. It follows, therefore, that, if the residual velocity at the extremity of the system is the same as that at the fan discharge flange, and if the entire conduit system is of uniform cross-section, the designer need not be concerned with velocity head at all. It is necessary only to determine the summation of the various resistances to flow in the circuit and the residual static pressure, if any. This is the static pressure required at the fan discharge and is the figure to be referred to the tables. However, if the residual velocity is greater than that at the fan discharge, the increase in velocity obviously must

be created at the expense of some of the static pressure. Therefore, the *difference* between the residual velocity head and that at the fan must be added to the other pressure losses to determine the static pressure required at the fan. Conversely, if the residual velocity is less than that at the fan, a gain in static pressure is made, provided the shape of the conduit is conducive to a favorable diffusion efficiency. An interesting example will illustrate the latter case.

In a recently erected boiler it was necessary to run the forced-draft duct for the wind box of the underfeed stoker through a small space in the wall, restricted by columns and other interferences. The velocity head through this orifice at normal operating rate would be nearly an inch water-gage, while the velocity head at the fan outlet would be only a fraction of that amount. Since space in the wind box is the least valuable of any space in the plant, a large diverging diffusion nozzle was designed, to be placed in the wind box, with the hope that it would reconvert into static pressure some of the pressure which was lost in the production of velocity head through the orifice. While this particular apparatus had not been accurately tested, a few approximate observations indicate that the diffusion efficiency of the nozzle is around 70 per cent. The saving in operating expense by reducing the duty on the fan by 0.7 inch is well worth the trouble and expense involved in obtaining it.

While considering the effect of velocity head it is pertinent to consider also horse-power determination, and to point out why velocity head need not be considered in determining fan horse-power.

The commonly used formula is, Shaft horse-power =

$$\frac{0.000158 \times \text{cubic feet per minute} \times \text{static pressure}}{\text{static efficiency}}.$$

This formula is of the same form as the familiar engine formula, Horse-power $= \dfrac{PLAN}{33{,}000}$, and is derived in an identical manner.

It is true that the numerator of the horse-power formula contains the term "static pressure." It expresses the "air horse-power" required to move a specific quantity of air against a specific static resistance in unit time, and it does not include the work absorbed in creating velocity head or the work of compression. However, the denominator of the formula is "static efficiency," which is defined as "the ratio of the theoretical air horse-power for delivery [only] to the actual shaft

horse-power when compressing and delivering air." Stated as a formula,
Static efficiency =

$$\frac{0.000158 \times \text{cubic feet per minute} \times \text{static pressure}}{\text{actual shaft horse-power}}.$$

Thus, the static-efficiency characteristic for a particular design of fan is determined by actual test at constant speed, varying the discharge opening and observing the volume, pressure, and horse-power. This characteristic can then be referred to other sizes and speeds for the same design, as explained by Estep and Carpenter. Since the denominator of the static-efficiency formula is the actual shaft horse-power when compressing and delivering air, the work of compression and velocity head are included in the horse-power formula. Therefore, to determine the shaft horse-power it is necessary only to determine the static pressure at the fan discharge required to overcome the various resistances and residual static pressure (considering the correction for residual velocity only if quite different from that at the fan) and to know the number of cubic feet per minute and the static efficiency of the fan corresponding to these values. Substitution in the formula gives the shaft horse-power, and this figure includes the work represented by velocity head.

Undoubtedly the most common error in the selection of fans for combustion service is inadequate allowance for leakage. Theoretically, ducts and conduits can be made perfectly tight, but actually even steam lines leak at some joints, and the care exercised in erecting air ducts and breechings is *nil* as compared to that exercised in erecting steam lines. Probably the worst offender is the junction of the breeching with the brickwork of the boiler setting. These joints are perpetually loose and are subjected to a high differential draft. A study of leakage as indicated by the drop in CO_2 in a flue-gas circuit from the furnace to the top of the stack shows a surprising amount of leakage throughout the circuit, and at the same time offers sufficient data to approximate the leakage from air ducts.

It is surprisingly common practice among plant designers to select a fan one or two sizes larger than the tables indicate should be required, giving the reason that leakage is one factor, but that fans seldom meet their guarantees. The writer disagrees both with the method and with the excuse. If the resistances are carefully calculated and manufacturers' draft-loss data checked or corrected for

excessive conservatism or optimism, and if adequate leakage factors are used, the fan which gives the optimum economic value is the one that should be installed, and an over-size fan results in an economic loss just as surely as an under-size fan results in capacity loss.

As proof of the fact that fans do meet anticipated performance (unless fundamentally defective) an example is offered.

The selection of fans for the recent addition to the Acme station for the Toledo Edison Company constituted a difficult problem. The forced-draft system was complicated by an air heater with high draft loss; an extensive duct system; 25-cycle speed limitation; the induced-draft system by the air heater, and the fact that a moderately high stack was to operate in series with the fan, the draft produced by the stack varying with the load on the boiler. The stoker was designed for maximum evaporation of 225,000 pounds an hour under specified operating conditions. The fans were selected for the same maximum rating, using the method outlined in this discussion. Following a series of 24-hour tests on the equipment, a five-hour, maximum-capacity test was run, during which the stoker drive and both fans were run "full speed ahead," without regard to the proper balance of pressure (with due caution, of course). The resulting actual evaporation when corrected to design feed temperature, etc., was 225,600 pounds an hour, and the furnace operated with a moderate negative pressure. While it is true that there were compensating plus and minus variations from calculated characteristics, the operating points for the various pieces of equipment, and especially the fans, fell remarkably close to the anticipated characteristics.

In conclusion, it may be said that the forced-draft and induced-draft fans are the lungs of a power-plant, and as such deserve the utmost analytical care in making a selection. This can be done only by a thorough understanding of the laws governing the flow of fluids and the characteristics of fans. If the analysis is left to the manufacturer's representative, who is a specialist, it is essential that he be given sufficient data on the nature of the installation to permit him properly to account for leakage, residual velocity, etc.

T. G. Estep: In regard to Mr. Orrok's statement that the characteristics given in this paper for the fan with forward-curved blades do not agree with some of his test data, the authors wish to make an

explanation. The tests from which our curves were plotted were made in the laboratory of the Carnegie Institute of Technology and, since the number of types of fans available was limited, the number of characteristic curves was also limited. We did not care to rely on field tests, because it is difficult to control all of the variables in such tests, but in the laboratory conditions may be varied at will and results are more satisfactory.

Mr. Orrok also states that we have not shown the series of curves giving the contours of equal efficiency. The authors did not feel that they were necessary in this paper. It might be mentioned, however, that in the laboratory work at the Institute the students are required to plot such curves, for they are considered very instructive.

It is difficult to say how far the theory of similitude may be carried. Its application to fan design is comparatively recent. It was first applied to the design of hydraulic turbines and later to centrifugal pumps. In England, Hodgson has applied this theory to the flow of fluids through orifices and his experimental work has been extensive enough to make it possible to predict results over a wide range of conditions. It is certain that the theory of similitude has a much broader application than that made at present and it is worthy of more careful study.

Just a few words more on the subject of fan selection for power-plant purposes. Mr. Van Deventer has shown the great care exercised in the selection of forced- and induced-draft fans for a certain power station. This form of analysis is going to be used more and more in the future. Large sums of money are being spent in our modern central stations to secure small gains in thermal efficiency. As long as exhaust steam could be used for feed-water heating, no particular attention was given to the efficiency of the draft fans, but with the advent of the regenerative cycle more thought is being given to the power consumption of the auxiliaries and fan builders must be ready to talk intelligently to power-plant engineers.

C. A. Carpenter: Referring to the question mentioned by Mr. Downes regarding the remark that, in general, inquiries do not mention the type of fan desired, but quite generally mention the capacity, pressure, and sometimes the speed, there has been apparently some misunderstanding of the purpose of the paper. I do not agree with the

idea that specification of capacity, speed, and pressure will fix the type of fan. As covered in the main body of the paper, capacity, pressure, and speed fix the specific speed. For a given specific speed there are corresponding fan efficiencies for various designs of fan. If the design of highest efficiency is to be selected, then Mr. Downes is correct in stating that the capacity, speed, and pressure practically fix the type of fan; but the relation between efficiency and specific speed should be considered because there are fan applications which, from practical considerations, fix the type of fan desired, and in many cases a more efficient installation can be made if the speed, for example, is left to the fan manufacturer so that he may offer a fan of the proper specific speed to make the efficiency for a particular design high enough to be satisfactory.

With reference to the subject of characteristic curves, published data of many fan companies indicate that both the static pressure and total pressure produced by a fan with forward-curved vanes will be higher at some operating point than at the point of total shut-off. This high portion of the characteristic curve of a forward-curved fan is one of the drawbacks to this particular type of fan for some classes of work. It is interesting to note that the apparent range in specific speeds for efficiency is very much less with a forward-curved fan than with a backward-curved fan. Therefore, under variable operating conditions, where widely different conditions are to be met, the backward-curved fan in most cases will work out better.

I agree with Mr. Downes in his statement that the size of the fan is important. In selecting a fan that is too large the efficiency at the point of operation is almost always low and, at the same time, if the speed be kept constant the fan is attempting to deliver more air through the system than is required, and this runs the horse-power up very rapidly.

A feature not mentioned in the paper might be mentioned in closing. The characteristic curves of fans may be varied by changing relative blade depth; thus, in a general way, the deeper the blade the higher the pressure curve. This is apparently due to the action of centrifugal force on the air passing through the fan wheel.

Mr. Orrok's discussion has been of great interest. The authors believe that the theory originally applied to water turbines, and more recently applied to centrifugal pumps, should certainly be applied to

centrifugal fans in order that some of the obscurity now evident in the recommendations covering fan equipment may be eliminated.

It is the hope of the authors that the efficiency field shown on Mr. Orrok's diagram may be worked out accurately for many different fans. This field indicates what might be styled the distortion in the theory of similitude. Mr. Van Deventer's comments are of special interest from a thoroughly practical standpoint. Mr. Van Deventer has shown in a very thorough way the problems that must be met by the user of fans, which problems expressed graphically show that the operating results desired do not conform to the same laws which apply to the fan at constant efficiency. Therefore, the selection of fans for power-plant use must be a matter of compromise and sound practical judgment.

In referring to the prevalent misuse or misunderstanding of the term "static pressure", and to Mr. Van Deventer's discussion of this point, the authors have in mind the difference in design dimensions of various fans offered for any particular job. Mr. Van Deventer is correct in calling attention to the fact that the efficiency accompanying a static-pressure capacity curve should be designated as static efficiency.

In approaching the application of a fan for a particular service it must be kept in mind that the first function of the fan is to overcome all of the resistances encountered in the path of the air. The summation of these resistances constitutes a basic static pressure. In addition to this, however, it is also necessary for the fan to produce the velocity required to keep the air moving through the system, more particularly applied to the velocity of the air when it finally leaves the system of airways encountered. It is true that many fan tables show the static pressures that a given fan will produce, and that in tables of this character there is a residual velocity head available at the discharge of the fan.

The point the authors wish to emphasize is the following. With a given fan application, competing fans may have radically different discharge areas. It is general to connect from the discharge outlet of a fan to the air system with a suitable connection so as to convert from velocity to static pressure, or vice versa, in an efficient manner. In such an application, a fan with a very large discharge opening as compared with a fan of smaller dimensions would show a lower total head if only static pressure at the discharge flange were considered. Since

both fans could be applied to identically the same airways it may readily be seen that in many applications the smaller fan would be more desirable and would do the work with the same total head as the larger fan, which would mean less static pressure at the discharge flange. The authors therefore believe that it is quite essential to distinguish between static head and velocity head in writing fan specifications; and that, in general, fans should be adapted to the particular duct system for which they are intended, without regard to any designation of static pressure at the discharge flange.

CHICAGO-BOSTON INTERCONNECTED TRANSMISSION SYSTEM*

By George S. Humphrey†

A few weeks ago I discovered to my great consternation that it is customary for the retiring chairman of each Section of this Society to be the speaker at the last meeting of his administration, which is the annual meeting for that Section. Consequently, you should bear in mind that when you elect a chairman you will not only have to put up with his presiding at each meeting throughout the year, but that you will also eventually have to listen to him for a whole evening.

In casting about for a subject which would probably be of interest to you and not require too much preparation on my part, I selected for the text an impromptu demonstration which I had a part in arranging last fall, and which may lead us along some interesting lines of thought.

The first alternating-current power-station in Pittsburgh was built on Broad Street in the East End, and put in service in March 1888. Other stations were soon built in Allegheny (now the North Side) and elsewhere in the Pittsburgh district, and also in Greensburg, Connellsville, Uniontown and other surrounding towns. At first considerable difficulty was encountered in operating units in the same plant in parallel, and it was necessary for each unit to carry certain circuits isolated from the other units, with makeshift switching arrangements to transfer circuits from one unit to another as required by changing load conditions. The operation of different stations in parallel was not even considered.

Shortly after this, the pioneers in our industry began installing larger units in central plants, using higher voltage lines to carry the loads of the smaller plants, which were gradually abandoned. In 1902 there were three distinct electric plants in operation in Connellsville. In 1903 a central station, large for that time, was put in operation at Connellsville, and 25-kilovolt lines were built from there to Greensburg and Uniontown, and gradually to other towns in the coke region. Again considerable difficulty was found in operating the original smaller plants in parallel with each other and with the new larger plant, these troubles being due largely to differences in prime movers.

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The next step, extending interconnections of the West Penn system, was made in 1917, when an agreement was made between the West Penn Power Company and the Duquesne Light Company of Pittsburgh to transfer load from one system to the other. The Duquesne Light Company found some difficulty in keeping its own plants in parallel during system disturbances, and it was almost impossible to keep the Duquesne and West Penn systems in parallel during disturbances, at this time, because of insufficient tie-line capacities. Mr. E. C. Stone gave considerable study to this subject, and in 1919 presented a paper on "Some Problems in the Operation of Power Plants in Parallel,"* in which he developed a formula for calculating the "synchronizing power" of transmission lines. The map, Fig. 1,

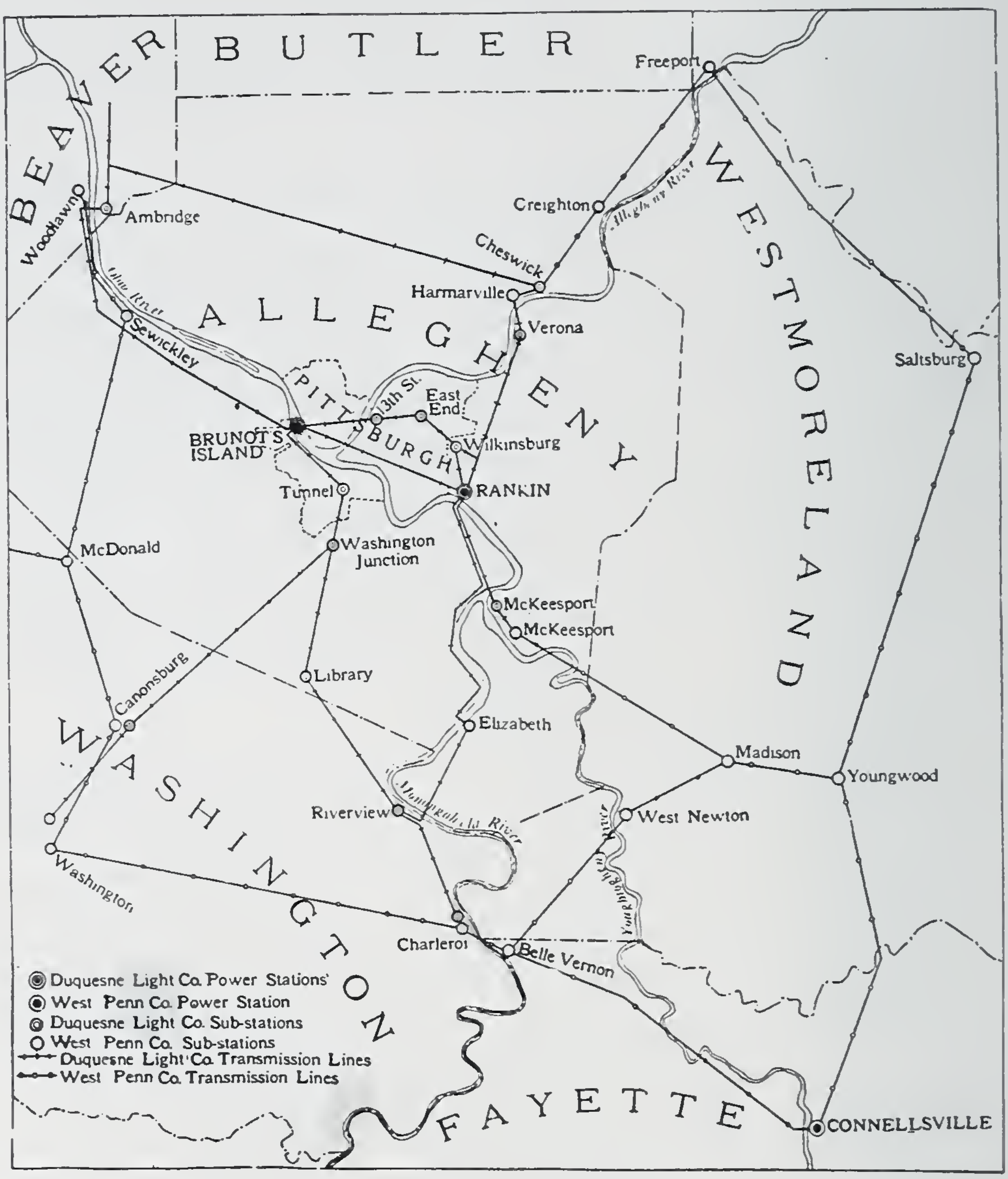

Fig. 1. Adjacent Lines of Duquesne Light Company and West Penn Power Company in 1917.

*Trans. A.I.E.E., v. 3, pt. 2, p. 1651.

which shows these two systems as they were just 10 years ago, is of interest as indicating the wonderful growth during the past decade. The Duquesne Light Company's load was then supplied by the Brunot Island and Rankin plants, while the West Penn load was supplied almost entirely by the Connellsville plant. There was no plant at Springdale, Windsor, Colfax, or Cheat Haven. It was found impractical actually to operate the two systems in parallel at that time except for periods long enough to transfer load from one system to the other. For example, the McKeesport load might be carried by the Duquesne system in the forenoon, during the West Penn normal peak, and by the West Penn system in the evening, during the Duquesne normal peak.

The first real interconnection made by the West Penn system involving parallel operation with another company was made in 1918, when the Windsor station was built jointly by the American Gas & Electric Company and the West Penn Power Company, and this brought us into parallel operation with Akron and eventually with Cleveland. The joint construction of the Windsor station by these two companies was a means of realizing the economy of a larger installation than either company would be warranted in making by itself, and was another way of arriving at the same advantage mentioned later as "alternate construction."

Within the past year the interconnection of companies in the district surrounding Pittsburgh was completed when a loop interconnection was made between the West Penn, the Duquesne Light Company, the Pennsylvania & Ohio Power, the Ohio Public Service Company, and the Ohio Power Company systems, as shown in Fig. 2. This interconnection is in the form of a ring, so that any system can receive help from one direction even though the connection in the other direction is out of service. It is a good example of interconnection, having all the typical advantages and operating problems.

It would perhaps be advisable to define "interconnection" before going further. Mr. Alex Dow, president of the Detroit Edison Company, recently gave a definition which seems to be a very good one. "Interconnection is the interchange of electrical energy between self-sufficient and self-contained electric systems." The idea of mutual assistance is paramount in a true interconnection. If a transmission line is built primarily to carry power in a certain direction during

Fig. 2. Five Interconnected Systems in Western Pennsylvania and Eastern Ohio.

normal operation, this would merely be transmission and not an interconnection. If a series of transmission lines is built connecting together several independent power systems as a series, these connections would not be interconnections if power is expected normally to flow in a certain way. The idea of mutual assistance in case of emergency must always be present in a true interconnection.

The arrangement described, whereby load was transferred back and forth between the West Penn and Duquesne Light systems without parallel operation, is not a true interconnection according to this definition. Parallel operation is necessary to get the full advantages from interconnection, so that in case of trouble one system may help to hold up the other without even momentary interruption. These two systems began parallel operation in 1926, with a 132-kilovolt line about two miles long (between Springdale and Colfax stations), which has ample synchronizing capacity to give stable operation.

There are two schools of thought on interconnections, one advocating a "loose connection," as used by the Detroit Edison Company; the other favoring a "tight connection," such as is used in most cases.

The loose connection provides for automatically breaking the system up into two or more major sections in case of trouble, so as to limit the effects of any one disturbance. This makes it necessary to carry on each major section sufficient generating capacity to carry the load that would be left on that section when isolated from other sections, whether or not this particular distribution of loads throughout the generating stations would be the most economical one. With the tight connection, a system is set up to cut out automatically any single station or section of line that may be in trouble, and hold all other sections together. In this way the load can be distributed among the power-plants to give the lowest production cost without so much necessity for maintaining a certain load on each plant regardless of operating costs. The tight connection seems preferable, provided it can be made to work successfully.

Advantages of Interconnection. The advantages of interconnections between systems are, in general, the same as the advantages of interconnection between different plants or parts of the same system, although they are even greater for interconnections between parts of the same system. The operating problems are also about the same for interconnections between different systems as for interconnections between parts of the same system, but are greater for interconnections between different systems. Interconnection was discussed a great deal during the World War, when it was necessary to do everything possible to get maximum production from existing equipment, and several interconnections were then made, including the one already mentioned between the West Penn system and the Duquesne Light system. The benefits of interconnection were then appreciated, but the difficulties were not realized.

The benefits realized from interconnection may be summarized as follows:

1. Saving in power-plant investment, due to the diversity of the loads between systems.

2. Saving in power-plant operating costs, by improvement in load-factor.

3. Saving in transmission investment and transmission losses, by carrying all load from the nearest power-plant and by eliminating unnecessary duplication of lines.

4. Improvement of service, by the mutual use of the systems of both companies for the benefit of either one in times of trouble.

5. Alternate construction—that is, one company making a large addition of generating equipment and selling some capacity to the other for a year or two, and thus making power-house additions in comparatively large blocks at greater economy than could be realized if each company independently installed new capacity.

The typical daily load curves of most large power systems are now quite similar; but yet there is considerable diversity between loads from day to day. One system may have its peak-load for one week at 10 a. m. on Tuesday, while a neighbor may have its peak-load for the same week on Wednesday. One system may have its winter peak in December, while another may have its winter peak in January or February. The benefit of diversity of load is even greater when the systems cover wide ranges of territory, taking in different kinds of industries and different time belts—for example, companies in the Eastern Time section connected with companies which are in the Central Time section; those in unionized coal fields, connected with those in non-union fields; plants in one watershed being operated with those in other watersheds, etc. Sudden increases in loads due to storms can also be handled more easily, as the storms would move from one system to another and not hit all of them at once.

The second advantage mentioned—saving in power-plant operating costs—is very marked in this territory, where there are generating units of various ages, where some plants are at some distances from coal-mines, where others are right at mines which are owned by the power company owning the plant, and where there are now several water-power plants in operation, with others to be built in the near future. Transmission systems have been constructed of ample capacity to allow load to be distributed fairly well to the power-plants which are most efficient at any time, even though they may be at considerable distance from load centers.

The third and fourth advantages mentioned were considerable, even when load had to be switched from one system to the other, as between the West Penn and Duquesne Light systems as described above. They are very much greater, however, when the systems operate in parallel, so that the load will seek its own path to give

minimum loss between the power-plants and the loads, and so that the resources of either system will be available to help the other in case of trouble, without even momentary interruption.

The advantage of alternate construction is illustrated by an agreement made about one year ago, whereby the Duquesne Light Company contracted to purchase 30,000 kilowatts from the West Penn system for one year, thereby postponing for that time a large additional investment which the Duquesne Light Company had under way at Colfax, and providing load for excess capacity which the West Penn system had temporarily, while its load increased to require the large additions to its generating equipment made during 1926. This made it possible for the West Penn system to realize the economy of installing generating capacity in comparatively large blocks sufficient to care for two or three years normal growth, and still get immediate use for the entire installation. The resulting savings realized by this arrangement were divided between the two companies.

Operating Problems. The principal operating problems arising from interconnection may be listed as follows:

1. Control of frequency.
2. Control of voltage, or flow of reactive kilovolt-amperes.
3. Control of flow of power.
4. Stability, both static and dynamic.
5. Limitation of disturbances.
6. Limitation of short-circuit currents.
7. Relaying.
8. Dispatching.

The first troublesome problem encountered was that of frequency. It was found that, although all of the systems involved were nominally 60-cycle systems, the average frequency was not the same, being slightly above or below 60 cycles for the different systems. Finally all agreed to operate at 60 cycles at all times as nearly as possible, and after the installation of Warren clocks by the various systems they were all finally made to read the same, and there is now very little difficulty about frequency. It is customary to assign certain loads for the various plants to carry, varying from hour to hour as conditions may require, having one or two plants (Windsor, which is

centrally located, being one of them) make a final frequency control as required by minor load changes.

Control of voltage, or of flow of reactive kilovolt-amperes is obtained very conveniently by the use of tap-changing transformers or regulators. For example, the West Penn 132-kilovolt system is connected to the Duquesne 66-kilovolt system at Colfax through a 36,000-kilovolt-ampere bank of transformers and a regulating transformer on the 66-kilovolt side, through which the voltage may be changed under load through a range of 10 per cent. above to 10 per cent. below normal by means of a control handle on the switchboard. By means of this regulating equipment either system may be made to take from the other any amount of reactive kilovolt-amperes, either leading or lagging, as may be desired. This is manipulated so that the system taking load does so at the average power-factor of its system load. If power is flowing from Colfax to Springdale, the Colfax voltage must be slightly higher than the Springdale voltage for this load to be transferred at a good power-factor; whereas, if Springdale is sending load towards Colfax, the Springdale voltage must be higher than the Colfax voltage to obtain good power-factor. These changes are easily made without any disturbances whatever to the system merely by manipulating a control handle on the switchboard at Colfax.

Control of the flow of power is a more difficult problem, which has not yet been solved satisfactorily. In fact, it seems impossible to make power go from one system to another as desired if the loop is kept closed. If the loop is open, say at Lowellville (Fig. 2), then the flow of power between Springdale and Colfax may be controlled within reasonable limits—that is, West Penn could reasonably well take, say 20,000 kilowatts from Colfax, or Duquesne could take 20,000 kilowatts from Springdale as long as may be desired. Likewise, if the circuit between Springdale and Colfax is open, the flow of power between the Duquesne and the Penn-Ohio systems at Lowellville could be controlled within reasonable limits. If, however, the loop is connected solidly at both points, it is impossible to control the flow of kilowatts as desired both between the West Penn and Duquesne systems at Colfax, and also between the Duquesne and Penn-Ohio systems at Lowellville. Consequently, for normal operation, the interconnection is made only at one of the two points,

usually between Springdale and Colfax, and the loop must be kept open at some point.

By stability is meant the ability to hold interconnected systems in parallel, and it depends on the voltage of the interconnecting lines, the size of conductors, and the capacity, characteristics, and location of generating equipment, synchronous condensers, etc. Static stability refers to the holding together of the interconnected plants with load changes usually obtained at normal operation, while dynamic stability refers to their holding together during short circuits or other violent system disturbances. Stable operation is obtained under all conditions by the systems shown in Fig. 2.

When one system is connected to another, it is affected not only by disturbances originating in itself, but also by those originating in the system to which it is connected. Consequently, more disturbances will come to a system which is interconnected with other systems than would be the case if it were isolated. Although the disturbances when interconnected are more numerous, they are not nearly as severe, and the net result is a large gain from the interconnection.

Short-circuit currents on oil circuit-breakers and other equipment are necessarily increased by interconnections, and this is a serious matter. From this standpoint it is really a good thing that transformers must often be used for interconnections, such as between the Duquesne 66-kilovolt system and the West Penn 132-kilovolt system, or between the Penn Public Service Corporation's 110-kilovolt system and the West Penn 132-kilovolt system. It would hardly be practical to connect the West Penn and Duquesne systems without intervening transformers, or some equivalent high impedance to limit short-circuit current from one to the other. With the arrangement as made, the West Penn system receives about as much short-circuit current from the Duquesne system as from its largest generator, and likewise, the West Penn interconnection at Colfax gives about as much short-circuit current on the Colfax bus-bar as an additional generator at Colfax.

Relaying interconnected systems, particularly those which have a number of power-plants and substations arranged in loops, is a rather difficult problem, but is being handled fairly well with the great variety of relays and systems of relaying which are available.

Dispatching the load for interconnected systems would seem, offhand, to be rather a difficult job, but it is really being worked out very satisfactorily by reason of the generous co-operation of the various load dispatchers, who operate on the give-and-take principle, realizing that the fellow giving help to-day may be the one who will need it to-morrow. Dispatching is being handled usually by co-operation between the various system dispatchers without setting up a central dispatcher having authority over the system dispatchers of the various interconnected systems.

The various operating problems mentioned, although more or less troublesome, are all being solved satisfactorily except, perhaps, the control of the flow of power in loops, and it is expected that this problem will also be solved in the near future, possibly by some means of phase shifting.

As an interesting example of the extent to which interconnection can be carried may be mentioned the connection which was established last fall between Chicago and Boston, which came about as follows:

On November 18, 1926, Mr. J. S. Jenks, vice-president of the West Penn Power Company, and several of his assistants went on a general inspection trip over the northern part of our system. On this trip we stopped at the Piney station of the Penn Public Service Corporation to witness the interconnection for the first time of the Penn Public Service Corporation system with the system of the West Penn Power Company. The construction for the interconnection at Piney had been completed at this time, but it was found that some further adjustments were needed. Consequently, the connection between these two systems was postponed until the following day, and the inspection party continued on to Ridgway. On the way from Piney to Ridgway it occurred to the writer that it was common practice for the West Penn system to operate in parallel with Chicago, and that it was also possible for the Penn Public Service Corporation system, through its connection to the north with the Niagara, Lockport & Ontario Power Company, to operate in parallel with Boston; and that if the proper connections were set up in advance, the closing of the oil circuit-breaker at Piney to connect the West Penn and Penn Public systems would at the same time connect Chicago through to Boston. That night I called Mr. E. P. Peck at Utica and told him about the arrangement we wished to make, and he agreed to have the

eastern section connected through for one hour between 11 a. m. and 12 o'clock the next day. Mr. J. E. Thomas, superintendent of operation for the West Penn Power Company, arranged through Mr. T. J. Williams, superintendent of operation for the Ohio Power Company at Canton, Ohio, to have the through connection set up in the western section.

When we arrived at Piney the next morning we started a check through the various system operators to the east and west to make sure that all connections had been set up, so that when we closed the oil circuit-breaker at Piney we would actually connect Chicago and Boston, instead of just thinking we were connecting them. It was found that one section of line was out of service for repairs between Shelby and Fostoria, Ohio, but the Ohio Power Company very kindly called off this work and put this line back in service in time for the test. Considerable time was consumed in making a check on the connections clear through in each direction, but finally at 11:47 a. m. information was received that Piney was in parallel with Boston and that West Penn was in parallel with Chicago. The Piney operator then closed the oil circuit-breaker which, for the first time, connected Chicago in parallel with Boston.

There was no disturbance and it was comparatively easy to control the power interchange between the West Penn and Penn Public systems within reasonable limits while the through connection was made. There was no evidence of hunting in spite of the 33-kilovolt line between Union City, Warren, and Falconer. This was probably due to the slip-type frequency changers at Falconer and Lighthouse Hill, which acted as flexible couplings between the 25-cycle Niagara system and the 60-cycle systems east and west of there. There is also a transmission line directly between Syracuse and Utica, which would offer a shorter route for the through connection than the one actually used. However, the frequency changer at Syracuse is not of the slip type and it is not possible to operate the interconnection through this frequency changer. The Penn Public Service Corporation system had been having some power-plant trouble that day and was operating on a rather narrow margin, so that it was thought best to cut loose from the interconnection after a few minutes, although there was no evidence of any trouble whatever.

A portion of the West Penn system was operating at 66 kilovolts

on the day of the test, but since that time it has been changed to 132 kilovolts, and it now operates at that voltage from Windsor through Charleroi, Springdale, and Piney to Ridgway. Within a short time the 132-kilovolt service will extend from Ridgway to Warren, and the line between Warren and Falconer will be put in service at 110 kilovolts. There will then be no circuits in the through line operating at less than 66 kilovolts.

Unfortunately there were several exaggerated and misleading descriptions of this connection carried by the daily newspapers, for which neither the writer nor any of his associates was responsible.

One of our engineers got curious to see just what could be done with a 132-kilovolt circuit (which is the highest voltage involved in the through connection) from Chicago to Boston. Such a line by the route used would be slightly less than 1500 miles long. He found that if stable operation could be obtained, a load of 1300 kilowatts could be transmitted over one 4/0 copper 132-kilovolt circuit from Chicago to Boston with 10 per cent. drop, the Boston power-factor being 60 per cent. lag and the Chicago power-factor 90 per cent. lag. This loss in transmitting the 1300 kilowatts would amount to 18,000 kilowatts. The voltage at Boston would be 180 degrees out of phase with that at Chicago. At no load it was found that for a line of this length the voltage at Boston would not be greater than that at Chicago, as would be expected because of the charging current. The voltage at no load would increase for some distance from Chicago and then would begin to decrease, this condition apparently being due to changes in phase angle over the long line. Of course, such a calculation has no real value, and is referred to merely as a matter of passing interest.

The power companies in the Pittsburgh district can now operate in parallel with a large number of other companies covering a territory extending from Chicago to Boston, and from the Great Lakes to the borders of North Carolina. A map (Fig. 3) has been prepared to show for this territory:

1. The name of each company and the lines and power-plants owned by each.

2. The name and capacity of each power-plant over 50,000 kilowatts, and whether it is a steam or water-power plant.

3. The voltage used by the various sections of the through lines.

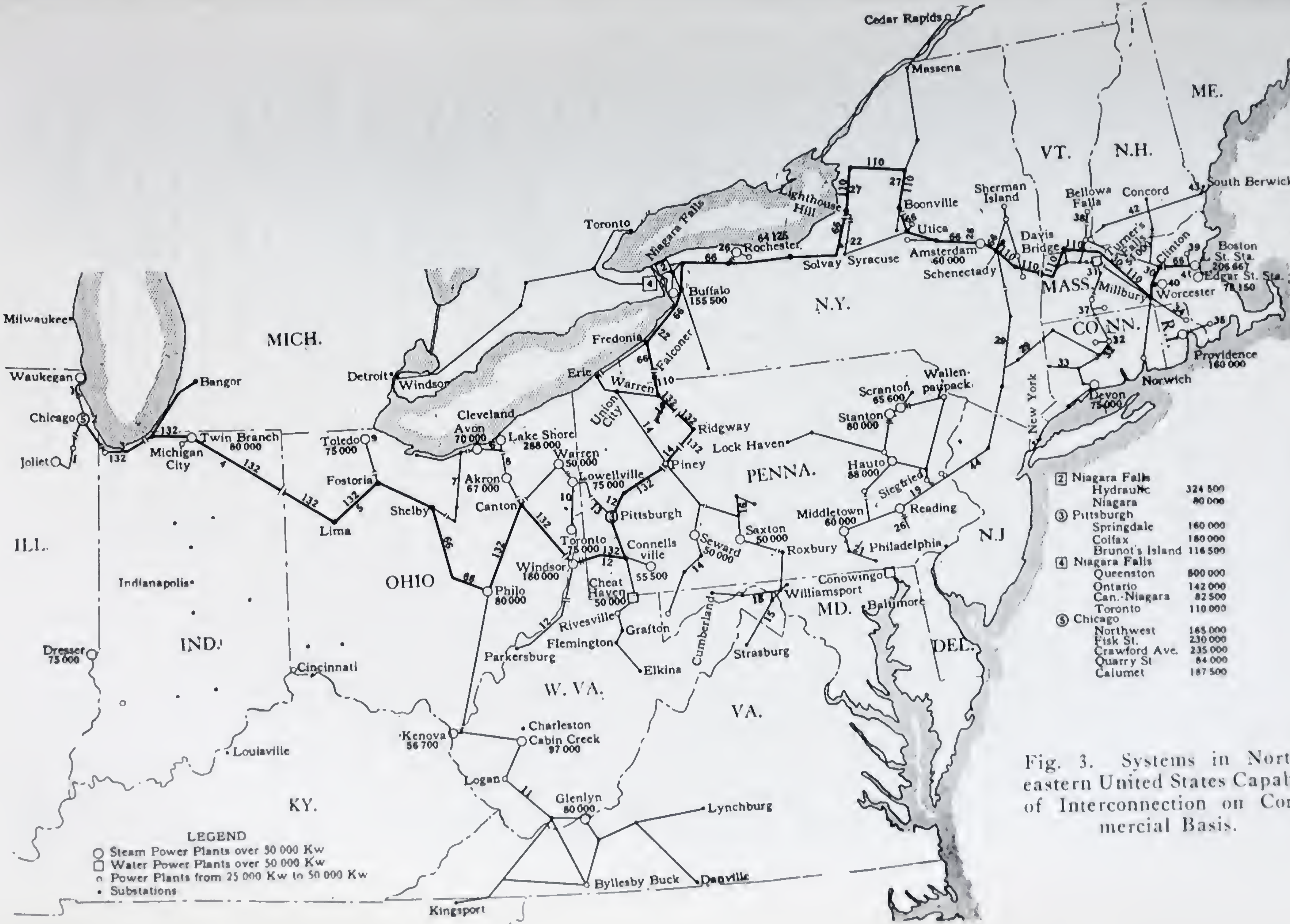

Fig. 3. Systems in Northeastern United States Capable of Interconnection on Commercial Basis.

4. The limits to which the parallel operation can extend in each direction, reaching into 11 states and Canada.

The systems are numbered (1 to 43) to agree with numbers in the list at the end of this paper. The other numbers on the lines refer to kilovolts.

There is a rather unusual arrangement in effect on this through line between Piney and Ridgway. A part of this line is owned by the Penn Public Service Corporation and the remainder by the West Penn Power Company, each company owning that portion of the line within its chartered territory. The Penn Public Service Corporation delivers into this line at Piney, power which is carried through Ridgway to its load at Warren. The West Penn Power Company also delivers into this line at Piney, power from Springdale and delivers it to West Penn territory at Ridgway. There is a 15,000-kilovolt-ampere autotransformer, with regulating transformer to control the flow of reactive kilovolt-amperes between the West Penn 132-kilovolt system and the Penn Public 110-kilovolt system at Piney. There is a similar autotransformer with a regulator at Warren. There is a delta-connected tertiary winding in the same tank with the autotransformer which excites three 2300-volt, single-phase, induction-type regulators, which in turn act on a three-phase series transformer in the leads of the 110-kilovolt autotransformer, and thus give a smooth voltage control to the extent of plus or minus 10 per cent. Equipment is being installed at Ridgway and Piney so that the regulator at Piney will be operated automatically by means of impulses over the private telephone line so that at all times the same reactive kilovolt-amperes will be taken from the West Penn system at Piney as Ridgway takes from the Piney-Warren line, compensation being provided for the charging current and reactive drop in the line. There are three I^2R meters at Piney—one in the West Penn Power Company connection, another in the Penn Public Service Corporation connection, and the third in the Ridgway connection, and the losses in the jointly used line are apportioned between the two companies in the ratio of the reading of the I^2R meter in each company's connection to the reading of the I^2R meter in the joint line. The generating capacity that can be operated in parallel amounts to approximately 7,650,000 kilowatts, as indicated by the list at the end of this paper.

The map includes only the systems which can operate with this through line with some fair degree of stability. Connection can be made with St. Louis over some low-capacity lines, through a frequency changer which is not of the slip type so that St. Louis can not be included. There are a number of plants in Illinois and Indiana which can be connected to the through line through low-capacity circuits, but which can not operate successfully in parallel. The Philadelphia Electric Company can also be connected to the through line, but can not hold in satisfactorily. The same condition is true for Baltimore and a number of the other adjoining systems.

Other connections are now being made quite rapidly all over the territory shown by this map. A 132-kilovolt line is being constructed from Waukegan to Milwaukee which will tie in a large territory in the northwest. Other lines are being built in Illinois, from Joliet to Springfield; in Indiana, from South Bend to Indianapolis; and in Ohio, from Cincinnati to Dayton, which will tie in considerable territory to the west. The Appalachian system is being extended to connect with the Carolina Power & Light Company in North Carolina, which will tie this whole northeastern group of companies in with the southeastern group. Plans are under way for connecting Conowingo and the Philadelphia Electric system with the Pennsylvania Power & Light Company and to connect with the Public Service in New Jersey and finally with New York City, and when these connections have been completed the capacities possible to interconnect will be counted in the tens of millions of kilowatts. The next man who undertakes to prepare a map of this sort has my sympathy, as he will have to cover practically all of the territory east of the Mississippi River and a large part of the country between the Mississippi River and the Rocky Mountains. It is improbable that all of the systems that can be interconnected will ordinarily be operated in parallel; rather, various groups will normally operate in parallel separate from other groups, but ready to change the normal arrangement as made desirable by changes in operating conditions from time to time.

Valuable as these interconnections are, it is quite possible to get an exaggerated idea of their value unless their limitations are kept clearly in mind. Due consideration must always be given to the ability of the neighboring company to supply power at the intercon-

necting point when needed. A good, strong interconnection is ordinarily about the equivalent of one spare unit. Interconnections for power systems should be considered somewhat in the nature of a second spare tire on an automobile. Every automobile should carry one spare tire. But if a person is going on an unusually hard trip, and his time is particularly valuable, he may take along a second spare tire; or each of a number of cars going on a long trip together may carry its regular spare tire and call on one of its companions, if it needs a second spare, on the theory that some of them will not even have to use one spare. In the same way, each power system should normally carry spare capacity sufficient to care for emergencies which occur rather frequently, but call on the interconnection to save it in case of some extraordinary emergency.

Quite recently there was a case of trouble in southern West Virginia which illustrates the way in which help is usually obtained from interconnections. I have heard this in two different ways and will tell them both.

According to the first explanation a line opened somewhere between Philo and Cabin Creek, leaving a load on the north end some 50,000 kilowatts more than the plants on the north end had been carrying. The frequency dropped a fraction of one cycle for a few seconds while the power-plants adjusted themselves to the larger load. No one knew anything about this except a few load dispatchers who could note from their Warren clocks that a few seconds had been lost. This loss was, of course, soon picked up by running just slightly above 60 cycles for a short time.

The second explanation was that the line opened at such a point that the power-plants on the south end were so overloaded that they could not raise the frequency quite enough to parallel with the plants to the north. Consequently, the plants to the north dropped their frequency slightly for a very short time to allow the plants to the south to synchronize, after which the frequency was carried slightly above normal for a short time until the Warren clocks indicated that the lost time had been made up. There are so many consumers' clocks now being operated by central-station service that it is necessary to control the frequency within extremely close limits, and make up for any time that may be lost during disturbances.

I think it will be of interest to note briefly some of the arrangements that have been made between interconnecting companies over various parts of the territory considered.

The Windsor power-plant is owned by the American Gas & Electric Company and the West Penn Power Company, each owning in fee one-half of the station. A third company, the Beech Bottom Power Company, all of whose common stock is owned equally by the two companies, leases and operates the entire plant and bills to them each month fixed charges and operating costs proportional to the kilovolt-ampere demand and kilowatt-hours used by each company. In case of emergency either company helps the other to the full extent of its ability to do so at the time.

The interchange agreement between the Duquesne Light Company and the West Penn Power Company provides that normally each company shall repay the number of kilowatt-hours received during any month; and that any balance shall be paid for on a straight kilowatt-hour basis. The kilowatt-hour rate is changed from time to time by mutual agreement. As previously stated, the West Penn Power Company is now selling 30,000 kilowatts to the Duquesne Light Company under a one-year contract, so that the Duquesne Light Company may delay the installation of additional generating equipment for a year, while providing use for temporary excess capacity which has been installed by the West Penn Power Company.

A very flexible arrangement which is in effect among several companies in New York state, and also between the Penn Public Service Corporation and the West Penn Power Company, provides that any company needing help will get it immediately, if available, and that the company furnishing help will inform the company receiving help within 24 hours regarding the rate which is to be paid for the power being received. This rate is subject to revision, after having opportunity to review various factors affecting the cost of production under the new operating conditions. Offhand, this arrangement may appear to leave the company which is in trouble to the mercy of its neighbor, but it actually seems to be quite satisfactory. The company which has spare capacity to-day may need help to-morrow, and consequently there is an earnest effort to be fair all around. The actual cost of producing a few thousand kilowatts additional varies considerably from time to time, and for this reason no rate for power was

specified in these agreements, leaving the way clear to fix the rate according to the actual cost of production at the time.

Interchange of power in the Connecticut Valley is discussed in the *Electrical World*, vol. 87, page 761; and the arrangement in the Chicago district is discussed in the same volume on page 1187.

The following power companies can now operate in the Chicago-Boston interconnection:

		Installed capacity in kilowatts
1.	Public Service Company of Northern Illinois	187,840
2.	Commonwealth Edison Company	960,500
3.	Northern Indiana Public Service Company	29,125
4.	Indiana & Michigan Electric Company	156,000
5.	Ohio Power Company	224,625
6.	Cleveland Electric Illuminating Company	358,000
7.	Ohio Public Service Company	110,000
8.	Northern Ohio Power & Light Company	67,000
9.	Toledo Edison Company	115,000
10.	Pennsylvania-Ohio Power & Light Company	150,000
11.	Appalachian Electric Power Company	331,276
12.	West Penn System (West Penn Power Company, 355,710)	435,615
13.	Duquesne Light Company	317,500
14.	Penn Public Service Company	162,850
15.	Potomac Edison Company	46,230
16.	Penn Central Light & Power Company	78,900
17.	Scranton Electric Company	145,500
18.	Pennsylvania Power & Light Company	235,000
19.	Metropolitan Edison Company	179,000
20.	Philadelphia Suburban-Counties Gas & Electric Company	108,200
21.	Pennsylvania Water & Power Company (60-cycle only)	49,000
22.	Niagara, Lockport & Ontario Power Company	74,000
23.	Buffalo General Electric Company	150,000
24.	Niagara Falls Power Company	487,000
25.	Hydro-Electric Power Commission of Ontario	752,000
26.	Rochester Gas & Electric Corporation	100,580

27.	Northern New York Utilities, Inc.	106,150
28.	Mohawk Hudson Power Corporation	321,150
29.	Central Hudson Gas & Electric Company	43,700
30.	New England Power Company	137,000
31.	Turners Falls Power & Electric Company	84,000
32.	Hartford Electric Light Company	83,000
33.	Connecticut Light & Power Company	124,000
34.	Blackstone Valley Gas & Electric Company	35,250
35.	Montauk Electric Company	30,000
36.	Narragansett Electric Lighting Company	160,000
37.	United Electric Light Company	32,000
38.	Bellows Falls Power Company	37,000
39.	Cambridge Electric Light Company	27,550
40.	Worcester Electric Light Company	71,000
41.	Edison Electric Illuminating Company of Boston	292,817
42.	Rutland Railway, Light & Power Company	21,225
43.	Public Service Company of New Hampshire	37,850
	Total	7,654,433

DISCUSSION

M. R. Scharff:* I came in very late and heard only a part of this very interesting paper. All I can say now is that the experience of the Duquesne Light Company since the 66,000-volt connection with the West Penn system and the Penn-Ohio system was put in operation during the past year has been most satisfactory. In several specific cases the advantages of reliability of service through interchange of power during interruptions have been strikingly exemplified; and in addition there has been a very concrete demonstration of the economy possible by alternation in installing additional equipment, to which reference was made in the paper. At the time the present contract between the West Penn and the Duquesne Light Company was negotiated, the Duquesne Light Company had under consideration the installation of 80,000 kilowatts at Colfax at an approximate cost of $8,000,000. Studies made at the time indicated that it was necessary to complete this installation and put it into operation in the fall of 1926. The negotiation of this contract made it

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possible to postpone the entire construction program for one year, thereby making a direct saving of the interest and fixed charges on that investment for one year's time. The contract also made it possible for the West Penn system to utilize capacity for which there was no other load in sight at the time. As stated by Mr. Humphrey, the contract between the two companies was based upon a sharing of the joint saving effected by this arrangement, and estimates of this saving at the time of the negotiation of the contract indicated that it would amount to the considerable sum of $280,000, or $140,000 for each of the companies involved.

T. J. WILLIAMS:* Mr. Humphrey called me yesterday and told me that he was giving a paper on the Boston-Chicago interconnection at a meeting to be held in Pittsburgh on this date and asked me, if I found it possible, to attend the meeting. I did not know at the time that I was expected to offer any discussion, and therefore made no preparation.

Mr. Humphrey called your attention to a case of trouble which occurred recently, and gave two reasons for this trouble. I wish to state that the second statement made was correct. When the West Virginia property was separated from Ohio, they were at that time receiving energy from the Ohio system. Being separated from the system, an overload was placed on the plants in West Virginia, causing a reduction in their frequency of a very small amount. However, the difference in frequency was such that West Virginia could not parallel and arrangements were made to reduce the frequency on the interconnected system a sufficient amount to allow West Virginia to parallel. It was necessary to reduce the frequency on this interconnected system to approximately 59½ cycles to meet the West Virginia frequency. By so regulating the interconnected system, parallel operation was possible without interfering with the load. Of course, if the West Virginia frequency had dropped to such an extent that it would not have been advisable to bring the interconnected system to it, it would have been necessary for West Virginia to drop some load in order to bring their frequency back to normal before they would have been able to operate in parallel.

I wish particularly to call your attention to the frequency maintained on this system. Mr. Humphrey did not have anything to say

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regarding it, but we have been (By we I mean all the operating organizations concerned in the interconnected system) congratulated on the frequency maintained. We are able to hold a frequency with a variation of 0.2 of a cycle or 0.1 plus or minus.

I recall one system which, previous to becoming a part of the interconnected system, was operating at a frequency of 61 cycles. When asked regarding this method of operation, a statement was made that they maintained a high frequency as much as possible so that in case of any difficulty in the system they could allow it to drop to 60 cycles, causing no difficulty to the consumers. Now you can readily see that when they dropped to 60 cycles, they would, in all probability, drop lower. They were finally induced to reduce their frequency to 60 cycles and become a part of the system, and I believe you could not separate them from the system.

Operating as a part of the interconnected system is very advantageous. There is not a plant on this interconnected system that has not been in trouble at one time or another and has called on the system for assistance. Only a short time ago we found it necessary to shut down our Philo plant on account of turbine trouble, thereby reducing the generating capacity on the interconnected system 80,000 kilowatts. During the period of shut-down no difficulty was experienced in carrying the load and the only persons concerned in this shut-down were the men in charge of operation. None of the consumers was inconvenienced. A short time later a case of trouble developed in one of the West Virginia plants, making it necessary to take two turbines out of service and reduce the load on the third turbine. This again caused a reduction of approximately 80,000 kilowatts, and again operating men were the only ones who were troubled in the least regarding the shortage of capacity, as the load usually carried on this station was distributed to various other plants. This we have found true in practically all cases of station trouble. There are times, however, when transmission-line troubles, accompanied by station troubles, will affect certain sections of the interconnected system. This can not be avoided.

George S. Humphrey: I should like to ask Mr. Williams to what extent the systems have been operating in parallel recently.

T. J. Williams: Owing to the fact that through the central part of Ohio the Ohio Power Company is operating with a small 66,000-volt line, we find it necessary to separate our system, allowing the west to parallel with Chicago. When this interconnection with Chicago was first tried out, considerable difficulty was experienced. Operating in the Chicago district are the Northern Indiana Public Service Company, the Public Service Company of Northern Illinois, and the Commonwealth Edison Company. These three systems had been operating as one unit and under one control. They had not been accustomed to maintain a stable frequency, as they had direct control of all the stations. Immediately on paralleling with the interconnected system it was found that they could not vary the frequency, but that considerable shifting of the load would take place. This shifting of load caused considerable difficulty through the central part of Ohio and there occurred in one day 108 switch outages due to this load transfer. After several conferences with the Commonwealth Edison Company and other companies operating in the Chicago district, we were able to operate the system as a whole from Chicago to Pittsburgh without difficulty except load fluctuation, which did not reach a sufficient value to cause any difficulty.

In the Chicago district there is a load fluctuation within a very short time of approximately 80,000 kilowatts, and you can readily see that unless this is controlled the excess capacity released in one section of the system must be placed on another part of the system, and this is what occurred. Recently we have been doing considerable line work throughout Ohio and we do not deem it advisable to operate in parallel with Chicago, so, previous to their coming in parallel, we separate the Ohio system either at Shelby or at Newark, Ohio.

It may be interesting to note that when this interconnection with the Commonwealth Edison Company at Chicago was first made, they endeavored to do all the regulating at the Calumet station. They, however, found that this was not feasible and arrangements were made whereby all the plants in the Chicago group would assist Calumet in regulating. Previous to the sudden changes of load, the stations, with the exception of Calumet, would reduce and allow Calumet a greater control. This method of procedure proved very successful, and I wish to state that as soon as our line-construction

period is complete we will, in all probability, again operate the interconnected system in parallel with Chicago.

George S. Humphrey: The Penn Public Service Company system at this particular time was in rather bad condition. There was trouble with a turbine at the power-plant near Johnstown, and we had to use all our persuasive powers to get the company in on this interconnection at all. The connection was made for only a few minutes, although everything held together and was stable. But the Penn Public engineer said, "You have had your fun, now I guess I had better get out," and so he did.

I would not attempt to maintain that Chicago and Boston could have stable regular operation in parallel over the connections as they were on that day.

With several million kilowatts of generating capacity on each side of the 7500-kilovolt-ampere frequency changer at Falconer, you can see that it could not stand very heavy load fluctuations, even though it is of the slip type. As long as everything was normal I imagine the whole interconnection could stay in parallel for quite a while because of the slip-type frequency changer or flexible coupling on each side of the Niagara system. If it had not been for these flexible couplings, I do not believe that the eastern and western ends would have stayed together at all; but having these two flexible couplings they were able to stay together with any fluctuations that did occur during this short time. However, I understand that the systems to the east of Falconer can operate together in quite a stable manner; also the systems to the west of Falconer can operate in a stable manner, or at least will be able to do so when the 132-kilovolt line mentioned by Mr. Williams is completed between Philo and Lima, Ohio. It is just the central point between the eastern and western sections where the connection is weak and experience is the only thing that will tell us just how these systems will get along with this arrangement. I understand that the Niagara, Lockport & Ontario Power Company is building a 60-cycle, 110-kilovolt line across its territory from Syracuse to Falconer, and that will give greater line capacity, but will eliminate those two flexible couplings provided by the frequency changers.

FACE PREPARATION FOR BLASTING COAL*

By B. L. Lubelsky†

The demand for lump coal created by the difference in market price between lump and slack has caused operators in the bituminous fields to study at great length the factors that enter into the breaking of the coal in the mine, at the face, in transit through the mine, or at the tipple. Since blasting of the coal is the greatest visible source of fine coal, this single operation has received great attention in the efforts to increase the proportion of lump coal produced and in the past few years several men in co-operation with the United States Bureau of Mines have investigated blasting in various parts of the country. The proper placement of drill holes, the proper explosive to be used, and the most desirable method of loading and tamping the holes have all been studied quantitatively in this state in research work conducted by the Carnegie Institute of Technology. Other factors such as the direction and width of working place, and the effect of different materials for stemming have also received careful consideration.

Throughout all the reports made by the men interested in the production of lump coal there is one operation connected with the mining of the coal which has received constant mention, not as a direct source of fine coal but as one of the factors seriously affecting the results possible in the proper shooting of the coal.

Face preparation, consisting of some form of mining of the coal prior to the shooting, for the purpose of creating an additional free face of coal towards which the shots may break and which will allow for the expansion of the coal after shooting, represents one of the earliest attempts made towards increasing the percentage of lump coal produced in the bituminous mines, and is one of the prominent factors in the production of lump coal.

Although at the present time all such mining is done by machines, of which there are several types, the essential purpose of the mining before shooting is the same as that which caused the miner to prepare his place by pick in the days before machines had been perfected or even before machines had been thought of. It is rather interesting to know that the first attempt at increasing the production of lump coal

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came not from the operator but from the miner. The operator, very early, when faced with a serious loss of revenue due to the price differential between the lump coal and the screenings, shifted the burden of responsibility to the miner by adopting the screen-coal basis of payment. Under this wage system the miner was paid for only that coal which passed over a bar screen. The first screens used in the Pittsburgh district were 1½-inch bar screens. Later the size was reduced to the 1¼-inch and finally to the ¾-inch bar screen. The miner was then directly faced with the problem of lump coal production since it materially affected his earnings and, as a result of this, attempted to reduce to a minimum the percentage of fine coal which he produced in his mining.

The practice followed in the "mining" of the coal as it was then called varied considerably in the various sections of the field. Fig. 1

Fig. 1. Undermining a Cut.

shows one practice which was prevalent in one section of the Pittsburgh bed. The miner undercut the coal by pick to a depth of five or six feet, cutting in below the binders since this was the softest coal. After cutting in about that distance across the face of the room, a good

many men would block down the coal below the binders by a small shot equivalent to the snubbing shot used at present. In other sections of the district the practice was slightly different. One man would mine the coal, starting between the bands, which were later named bearing-in bands due to the fact that miners started their bearing in or mining between these bands. At the same time that the one man was mining the coal, another man would be shearing back his tight side so that the face preparation in this district consisted of undercutting and side shearing, although both were done by pick.

Although the miners were, of course, interested primarily in the production of lump coal and resorted to this extra work on that account, this mining of the coal before shooting was made a part of the first mining law of Pennsylvania, in 1877, which stated that all coal should be properly undermined before shooting. The reason for this was the fact that shooting off the solid was the cause of a good many blown-out or windy shots that were rightly recognized as a potential danger in any gaseous or dusty mine.

It is especially interesting to know that, although the law took notice of this danger and required undermining of coal before shooting, it was a good many years after the passage of the law before it was made effective except in those mines requiring lump coal. The contention of the coke region operators, when faced with the problem of undermining the coal, was that proper mining referred to those mines producing lump coal for the market. As late as 1913 in the report of the Department of Mines of Pennsylvania the Director found it necessary to explain the fact that the coke region operators were not undermining the coal in all mines before shooting.

Representatives of the United States Bureau of Mines, and other authors, have repeatedly recommended that cuts should be made with ribs as straight as possible—not gripped; that in this district, especially, places should be cut on the face; and that all "bug dust" should be removed from under the cut before shooting. These suggestions are important since they are the result of considerable study and the effect of these factors deserves discussion.

In passing from the hand mining to machine mining of the coal before shooting, no great consideration was given to the size of the kerf which would give the best results in shooting. The six-inch kerf which has become almost a standard for the present machines was

developed entirely for mechanical advantages in the design of the machine. The percentage of fine coal which is produced through the actual cutting is, of course, a function of the height of the bed being worked. A six-inch kerf in a five-foot bed of coal represents the production of 10 per cent. of slack; whereas, in a nine-foot bed, it represents only 5½ per cent. Since the purpose of the cut is to allow room for expansion of the coal upon shooting, to prevent excessive shattering and crushing, it is obvious that the six-inch kerf which is hardly sufficient to allow for normal expansion of the coal in the five-foot bed would be entirely inadequate in the nine-foot bed. If this six-inch kerf is further reduced by negligence or incompetency of the

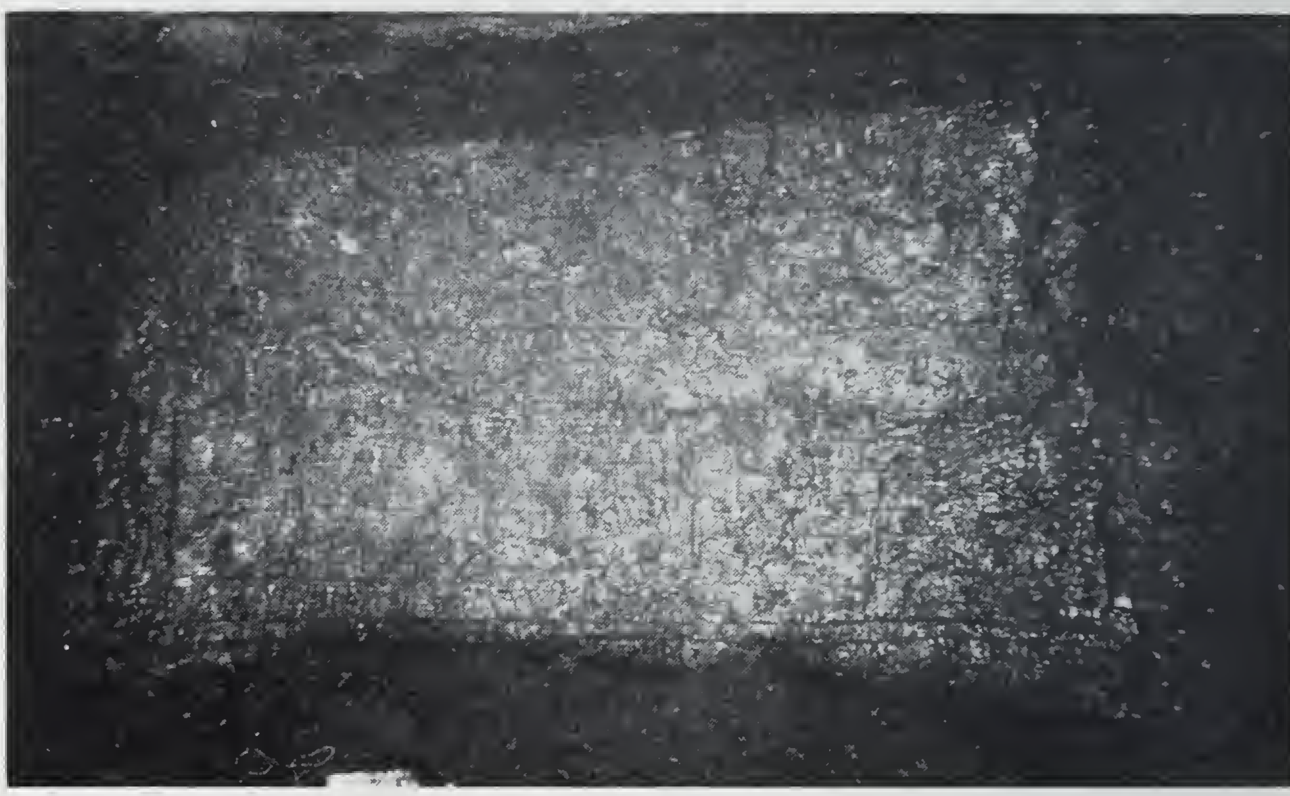
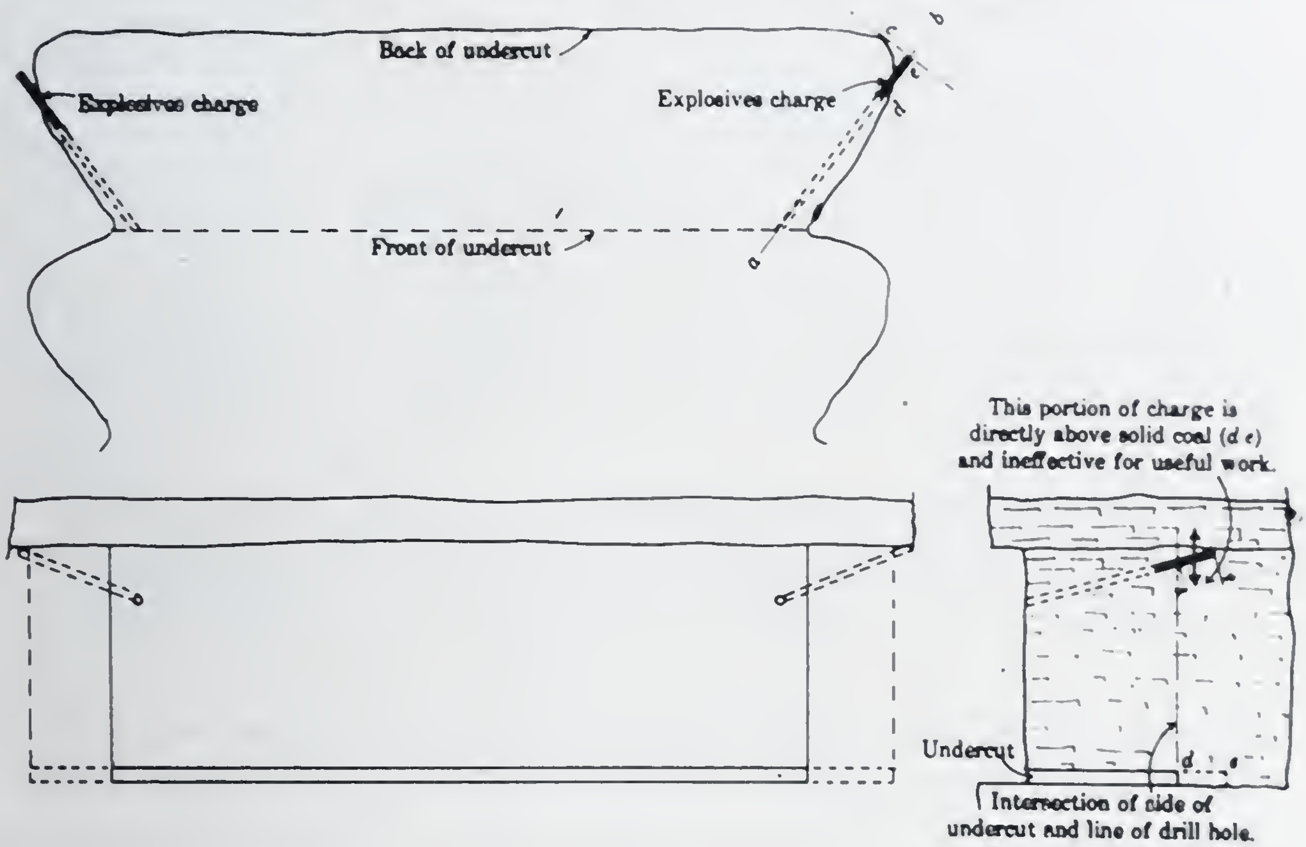


Fig. 2. Machine Cuttings Shoveled from Cut.

machine men, the shooting is being done under conditions which closely approximate solid shooting. The "bug dust" which is pulled back by the machine chain packs tightly at the back of the cut, and in going through the mines it is not uncommon to find considerable overhang at the face with a pot-hole blown into it showing that the hole was drilled over that portion of the cut which was practically solid due to machine cuttings. Fig. 2 shows the amount of "bug dust" which was shoveled out of an ordinary cut with a long-handled shovel, before shooting the tight shot.

This condition is common to all types of undercutting machines and, unless the scraper shovels back the dust as fast as it is cut, it is essential for the miner to use a long-handled scraper or shovel if he is to get the best results with his shot. Since no cut can justly be considered complete until the coal has not only been cut but also removed from under the cut, it would seem that this should really be part of the duty of the machine crew instead of the miner.

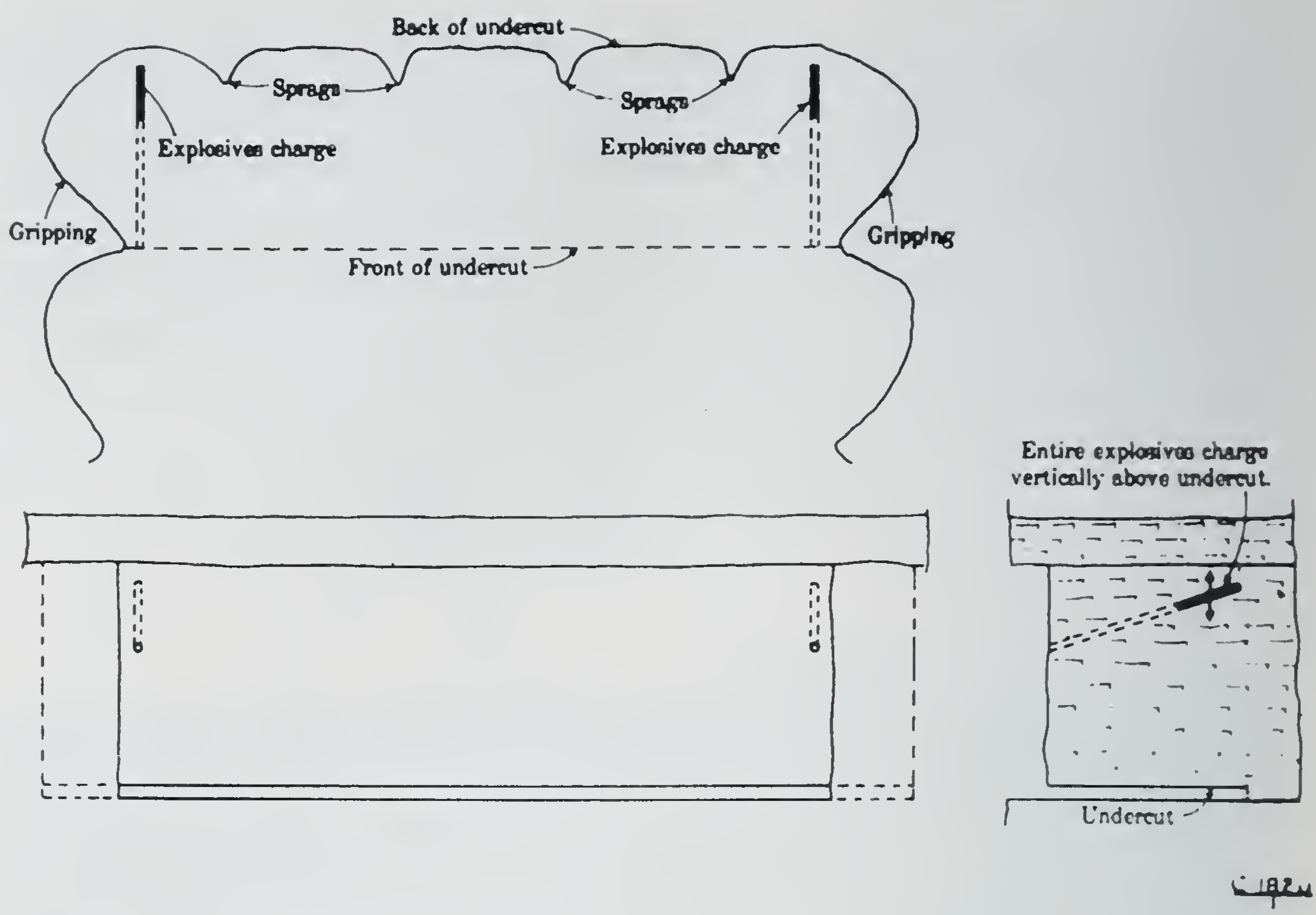


Gripping undercut made by shortwall machine showing holes drilled on the solid.

Fig. 3. Sketch Indicating Stumps Left When Cutting with Breast Machine.

Fig. 3 shows a condition which is very often found where the breast machine is used. In sumping in after each run, a careless or incompetent machine man will leave stumps between the runs that act as sprags against the shot and make it difficult to bring down the coal with a normal charge of explosive.

Gripping at the ribs, as illustrated in Fig. 4, is one of the most serious obstacles that must be overcome in obtaining good lump coal shots. As shown in the figure, the cut has been gripped and the miner following the line of the cut with his hole has the hole in the solid. Of course the cut is not responsible for the hole, but it is true that when the cut is gripped it is difficult to prevent the miner from gripping the



Undercut with breast machine showing sprags and gripping at the ribs.

Fig. 4. Sketch Indicating Gripping at Ribs in Cutting with Short-Wall Machine.

drill hole and a large percentage of these holes go into the solid either at the back of the cut or at the rib. With this type of cut, the explosive charge is located behind a solid point of coal and causes considerable shattering in the wedge behind this point. Also the shot, instead of shearing the coal along the butt cleat, will shear close to the rib, or in many cases will not produce a good shear but will merely crush that coal at the back of the cut, leaving the front of the cut solid. In order to get the coal it is necessary for the miner to dig through almost solid coal until he reaches the crushed section.

In addition to the extra work involved and the extra slack produced through unnecessary pick work, it is often difficult to shear the tight shot completely, and so the butt shot will be fired before the tight has been cut through, leaving from one to two feet of coal at the back of the cut. On the following cut the machine man is forced to cut shorter on that side with the result that the back of the cut is off face.

Off-face cutting—that is a cut that is at an angle to the face cleat of the coal—is also caused by carelessness on the part of the machine

runner in cutting across the face before the machine is sumped into the full length of the cutter bar, or in cutting a break through and a room without pulling the machine out after the first cut and resumping for the second one. By swinging the machine into the room after cutting the break through, the effect of an arc-wall cut is obtained, and one side of the room will be rounded and several feet ahead of the other side.

In shooting the coal of this district the face cleat which is extremely well defined is probably the greatest existing aid in producing good lump coal. This face cleat allows the coal to break freely at the back of the cut with no overhang, using only a small amount of explosive. With off-face cutting, the coal tends to break along the line of the face cleat nearest the end of the hole, with the result that coal behind this cleat can not be brought down with the regular two shots. This necessitates either pick work or pop shots to trim up the face of the working place.

The arc-wall machine has been designed for the special purpose of cutting at points of the bed of coal other than the bottom, to cut out a binder of soft material at some section of the bed, or to cut near the top in order to leave some top coal for roof support. Undoubtedly there is a considerable advantage to be found in the use of an arc-wall machine under certain conditions. The cutting out of a soft binder is a saving in mining, and where the binder is too hard to be cut into by the machine it is possible to cut either above or below the binder and remove it before loading the coal, effecting a saving in work, and producing a cleaner product.

In the Pittsburgh district, however, the use of the arc-wall machine has been limited to leaving top coal in place for protection of the draw slate. The protection afforded by the coal against air reaching the draw slate is a very material one and under ordinary conditions it is possible to effect a great saving in cost as well as an increase in production by eliminating the handling of the draw slate.

In those mines loading screened coal, the saving effected by eliminating the handling of the slate must be balanced against the possibility of producing a marketable product before such a machine can be adopted. The arc-wall machine, cutting as it does across the face of the coal, offers a serious handicap to shooting, and in spite of its other advantages in mining it leads to difficulties in this respect. With the

standard two-hole system of shooting as described, there are two natural aids that are taken advantage of to produce lump coal. The face cleat is utilized as a breakage line for the coal at the back of the cut and as a result the explosive charge required in places working on the face—that is, at right angles to the face cleat—is noticeably less than that required in other coal fields which do not have a very clearly defined cleat. The other natural aid used in shooting is the weight of the coal itself. Although there are many writers who have stated that it does not require more explosive to shoot up than it does to shoot down in a coal cut, there is evidently one point which they have overlooked. In those mines producing lump coal, the tight shot is charged so that the coal will be cracked along the horizontal bedding planes. The tight shot is not supposed to set the coal down against the bottom of the cut. After the place has been shot the miner shears to the back of the cut with his pick, following the powder crack or shear which is produced by the shot. In this operation the weight of the coal is a very distinct advantage, as every time the pick strikes against the coal and loosens it, the weight of the coal tends to help the coal break away. For this reason a good miner, even though shooting his own cut, does not charge the tight shot very heavily.

With the arc-wall top-cutting machine, both these aids are eliminated. In the first place, the cut is made across the face cleats, eliminating the advantages of a free parting face cleat and practically assuring the necessity of an extra drill hole in order to bring down the coal. The weight of the coal is acting away from instead of towards the cut so that any pick work done by the miner towards cutting to the back is done without the help of the weight of the coal. For this reason it is absolutely necessary to shoot the opening shot, whether it be a center or a rib shot, heavy enough to crush the coal so that the miner can load it. If the regular two-hole system of shooting were to be used with the top cut, the tight shot would tend to break along the line of the face cleat at the back of the hole, and in almost all cases the coal in the center of the cut beyond this face cleat would be solid. In order to mine the coal properly a center shot is almost always necessary, either as an opener shot or as a trimmer after the two rib holes have been fired. In either case the extra hole is productive of additional fines.

Recently another type of cutting machine designed especially as an additional aid in face preparation has been gaining prominence in mining. The vertical shearing machine in addition to either the bottom or top cut serves several purposes well. In mechanical loading, especially, the shearing machine has found an important place, as the success of mechanical loading depends to a large degree upon the ease of loading. With either the top or bottom cutting machine it is difficult to shoot the coal so as to allow the machine to load out an entire cut without encountering solid coal. Unlike the miner digging the coal out, the machine must find the coal ready for loading. For this reason the shearing machine has proved an important aid in face preparation. The vertical cut allows the first shot to have an extra face towards which it can break, and eliminates the wedging which is characteristic of the opener shot. The vertical shear is used as a center cut, slightly off center, leaving a block of coal in the center supported at the back and top only and two small blocks or shoulders on the rib supported on the rib top and back. The center block in this case is broken up with one or two small shots and the shoulders require one light shot each. Undoubtedly the advantage in ease of loading and in the decrease of the explosive charge required is an important one, and if these factors are the important ones for consideration the machine has a very valuable function; but in those mines hand loading the coal and requiring lump coal there is considerable room for argument as to the merits of the shearing machine. Although many reports claim as high as ten per cent. increase in production of lump coal due to the introduction of the shearing machine, it is difficult to see how such a result is obtained in this district.

Factors which affect the production of lump coal are discussed in Bulletin 19 of the co-operative coal-mining investigations under the auspices of Carnegie Institute of Technology, the United States Bureau of Mines, and the Advisory Board of Coal-Mine Operators and Engineers. In these tests, the tight shot was fired first after the "bug dust" had all been loaded out, and all the loose coal brought down by this shot was loaded out before firing the butt shot. Each car was weighed in the car, then dumped and screened, and the weight of lump coal taken in the pan. The empty cars were also weighed so that it was possible to obtain a very accurate record. The coal from the butt shot was kept separate from that of the tight shot in all tests

conducted during the year. In going over the results published, it is significant that about one-half the coal was mined from the tight shot and the remainder from the butt shot. The tight shot produced an average of four per cent. less lump coal than did the butt shot. Since the butt shot as shown in Fig. 5 represents the best condition of blasting coal open on three sides it is doubtful whether the shearing machine will enable the production of lump coal from the tight shot equal to that produced by the butt shots. However, assuming this to be true, with a shearing cut it will be possbile to increase the lump

Fig. 5. Lump Coal Produced by Butt Shot.

coal produced from the opener shot about four per cent., and, since this represents only one-half the cut, an increase of two per cent. for the entire cut is all that can be expected. Since the shearing machine cuts a kerf of a minimum of four inches the additional slack produced in a 20-foot room would be about 2½ per cent. Obviously, the slack produced by the machine would offset any advantage that might reasonably be expected on the basis of these figures. There may, however, be some difference in the production of the large lump coal so much desired for domestic use, and this might prove advan-

tageous. This would of course depend largely upon the conditions found in the individual mine.

DISCUSSION

L. O. LOUGEE, *Chairman*:* Gentlemen, you have heard a very interesting paper. Is there any discussion, or are there any questions you wish to ask the speaker?

N. A. TOLCH:† I would like to ask the speaker why it is that hand snubbing is an advantage with coal that is less in height than the depth of the cut.

B. L. LUBELSKY: I do not know just how clear I can make that, except to say that the general experience has been that where the height of the coal is less than the depth of the cut, there is a natural tendency for the entire cut to fall down and out, and when you snub it it allows the coal to roll out. Where the height is greater than the under cut, the tendency is rather for the side to go down; it does not have the same weight pivoting it outward as you have in the first case.

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ECONOMIZERS*

By Walter F. Keenan, Jr.†

In this paper no effort has been made to discuss at length the relative merits of air heaters and economizers, but, as they are competitors in the same field, it does not seem possible to discuss economizers without some reference to air heaters as well. However, any comments adverse to air heaters are based not on a willingness to criticize, but solely on a desire to state fully the economizer point of view.

An economizer is a device in which heat absorbed from flue-gases leaving the boiler is utilized to reduce the work that must be done in the boiler per pound of steam generated. This is accomplished by transferring heat from the flue-gases to the feed-water as it is pumped through the economizer before entering the boiler. For the same amount of fuel burned, this results in an increase of capacity that is in the same proportion that the total heat added to water and steam in the boiler, superheater, and economizer is to the heat added in the boiler and the superheater; or, for the same amount of steam generated, it results in a saving of fuel that is in the same proportion that the heat added in the economizer is to the total heat added in the boiler, the superheater and the economizer.

Economizers have been used abroad and in this country for about 75 years. The earliest form of economizer was apparently one constructed by John Smeaton in England in 1765. This was a copper jacket surrounding the side discharge duct for furnace gases from an internally fired boiler consisting of a fire-box surrounded by a drum containing steam and water. This was designed for a working pressure of two pounds per square inch. The Green cast-iron economizer was first built in Wakefield, England, about 1850. The Herreshoft boiler, which was designed about 1879, included continuous coils of wrought-iron pipe for feed-water heating. These were arranged in the form of a cone, with the space inside forming a combustion chamber. Later, the Belleville water-tube boiler was developed with a horizontal tube economizer in the boiler uptake. This was first used in the British Navy about 1890.

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Cast-iron economizers were extensively used in this country until about 1920. The latest types of these economizers consist of vertical cast-iron tubes of about 4½ inches external diameter spaced eight inches from center to center transverse to, and about seven inches from center to center parallel to the flow of gases through the economizer. Cast-iron tubes are attached by means of pressed, or rust, joints to cast-iron headers at top and bottom which are connected by flanged joints to the outlet and inlet manifolds.

This type of economizer is often arranged in large units to which the waste gases are brought from a number of boilers. By-pass flues and dampers are usually installed so that the economizer can be operated with any one or more of the boilers to which it is connected, or can be shut down independently of the boilers. Tubes are cleaned by mechanical scrapers driven by operating mechanism located on top of the economizer setting. This type of economizer is not suitable for high pressure. Air infiltration through by-pass dampers and dampers to boilers not in operation, through long flues, and through holes for cleaning mechanism, is excessive. In order to minimize air infiltration it is necessary to design for low gas velocities, and this means that only low rates of heat transfer are obtained. Economizer installations of this type require a great deal of space. This, and expensive flues, with low efficiencies due to low rates of heat transfer and excessive losses by radiation and air infiltration, have made it unsatisfactory for present-day conditions. In this country, at least, very few economizers of this type are now being installed.

The next important economizer development was that of the steel-tube integral economizer. This type usually consists of a bank of boiler tubes expanded into inlet and outlet drums. In some cases, economizers of this type have been built up of horizontally inclined tubes expanded into sectional headers the same as horizontal water-tube sectional header boilers. More installations of this kind have been made in vertical than in horizontal water-tube boilers. The reason for this probably is that in a given furnace width, the size of vertical boilers can not be increased as easily as the size of horizontal straight-tube boilers; and also that, at high ratings which usually prevail when economizers are installed, exit gas temperatures are likely to be higher from vertical than from horizontal straight-tube boilers. In addition, an integral economizer can be built into a vertical

boiler setting more advantageously than into a horizontal straight-tube boiler setting.

The integral type of economizer can not well be baffled to obtain the high rates of heat transfer that will result from cross flow of gas at high velocity over economizer heating surfaces; nor can it well be arranged for full counter-current flow of gas and water through an economizer as required to take full advantage of the additional heat available for absorption in the economizer by reason of the fact that the temperature of water entering the economizer is lower than the temperature of water and steam in the boiler.

If the average velocity of water passing through an economizer is not above some critical velocity there will be recirculation of water within the economizer. With recirculation the average mean temperature difference will be less than with full counter-current flow of gas and water, and the amount of heat absorbed by the economizer will be less in proportion.

When there is recirculation there is in storage in an integral economizer a certain weight of water which is usually at some average temperature between the temperature of the incoming water to the economizer and the temperature of steam and water in the boiler. This body of water is cooled by radiation to adjacent cooler surfaces, and by cooler incoming water. It is heated by gases passing over heating surfaces with which it is in contact, and by condensation of steam at surfaces where it is in contact with steam formed in the boiler. The average temperature of the recirculating water is that temperature at which the cooling effect of radiation and cooler incoming water is balanced by the heating effect of cooling gases and condensing steam. In such an economizer the heat apparently absorbed from furnace gases as measured by the weight and the rise in temperature of the water in and out of the integral economizer is greater than the heat actually absorbed as determined by the weight and the temperature drop of gases in and out of the integral economizer section.

An example of this is included in the Prime Movers Committee report on boilers, superheaters and economizers issued in April 1927, by the National Electric Light Association. This is a summary of test results at the Richmond station of the Philadelphia Electric Company.

According to this report, the excess air at the last pass of the

boiler varies from about 30 per cent. at 100 per cent. rating to about 13 per cent. at 300 per cent. rating. The average air required per pound of dry coal is 10.9 pounds, and the gas temperature drop through the integral economizer is 130, 135, and 145 degrees at 100, 200, and 300 per cent. rating, respectively. The weight of combustible and moisture is 0.92 pound, and the B.t.u. value is 13,900 per pound of coal as fired. Using a specific heat of 0.24 the difference in heat content of the gases in and out of the integral economizer at 100 per cent. rating is 3.3 per cent., and at 300 per cent. rating, 3.1 per cent. of the heat in the coal as fired. The heat absorbed by the economizer is reported as varying at different ratings from 3.9 to 4.9 per cent. of the heat in the coal as fired. These figures show that the heat added to the water is 37 per cent. greater than the heat extracted from the furnace gases by the integral economizer. The probable explanation is that this additional heating is due to condensation of steam from the boiler and not to cooling of gases by the integral economizer.

The unit steel tube with extended surface is the most modern type of economizer. It is set independently of the boilers, and is designed for water velocity sufficient to insure positive counter-current flow of gas and water, and high gas velocity as required for high rates of heat transfer. Fig. 1 is a view of a Foster economizer. An element for this type of economizer is shown in Fig. 2.

Important design requirements for this type of economizer are discussed in the following paragraphs.

Unit Setting. Each boiler is equipped with its own economizer, with the shortest possible connecting flue and without by-pass dampers to provide for independent operation of the boiler and the economizer; in other words, the economizer is a part of the boiler unit. This arrangement is practicable from an operating standpoint because the steel-tube unit-type economizer is not subject to troubles that would cause an unexpected shut down of the boiler unit; and because any necessary inspection, cleaning or repair of the economizer can be conducted when the boiler unit is down for other causes. As compared with the old-style cast-iron economizer which it has superseded, this arrangement greatly reduces total space requirements and also the cost of dampers and insulated flues and practically eliminates heat

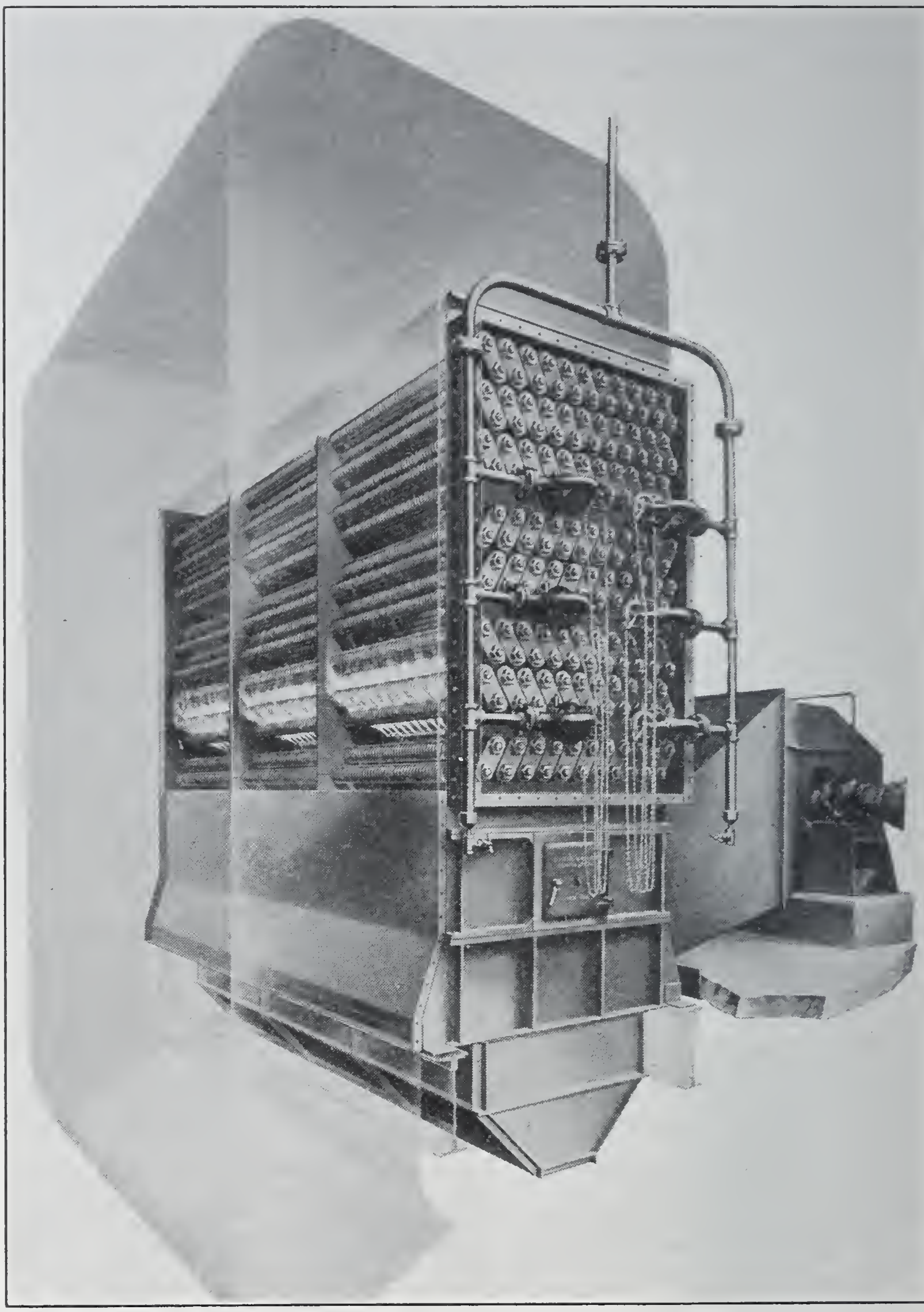

Fig. 1. Phantom View of Typical Foster Economizer.

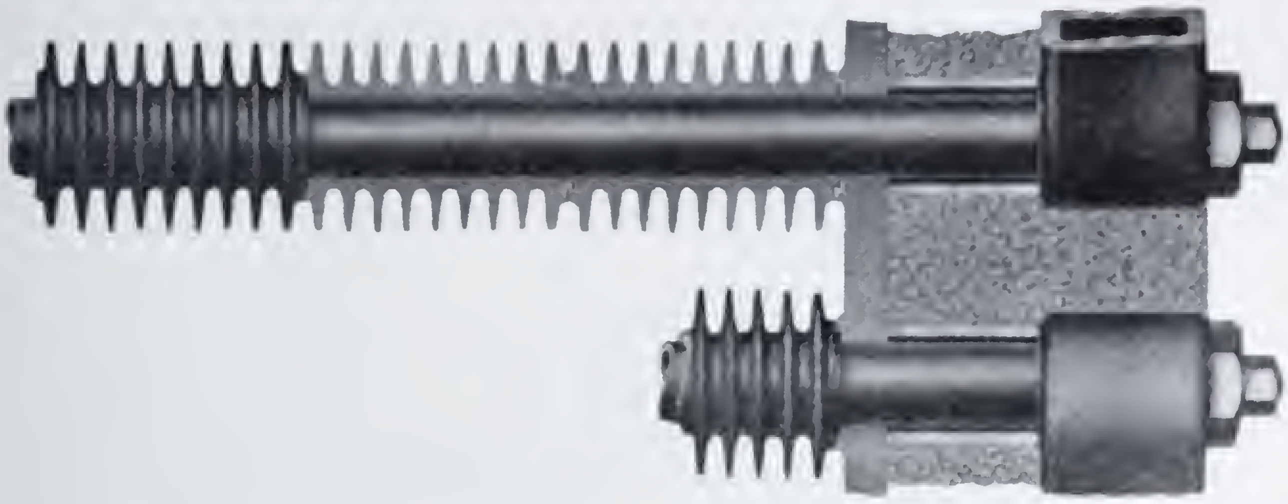

Fig. 2. Detail of Element for Unit Steel-Tube Economizer with Extended Surface.

losses due to radiation and air infiltration between the boiler and the economizer.

Design of Casing. Operation at higher steam pressures and higher ratings which is characteristic of modern boiler-room practice results in higher gas temperatures and high suction pressures to be handled in economizers. Under these conditions in order to eliminate air infiltration into the economizer and reduce heat losses by radiation, it is essential that economizer casings be of a substantial, rugged con-

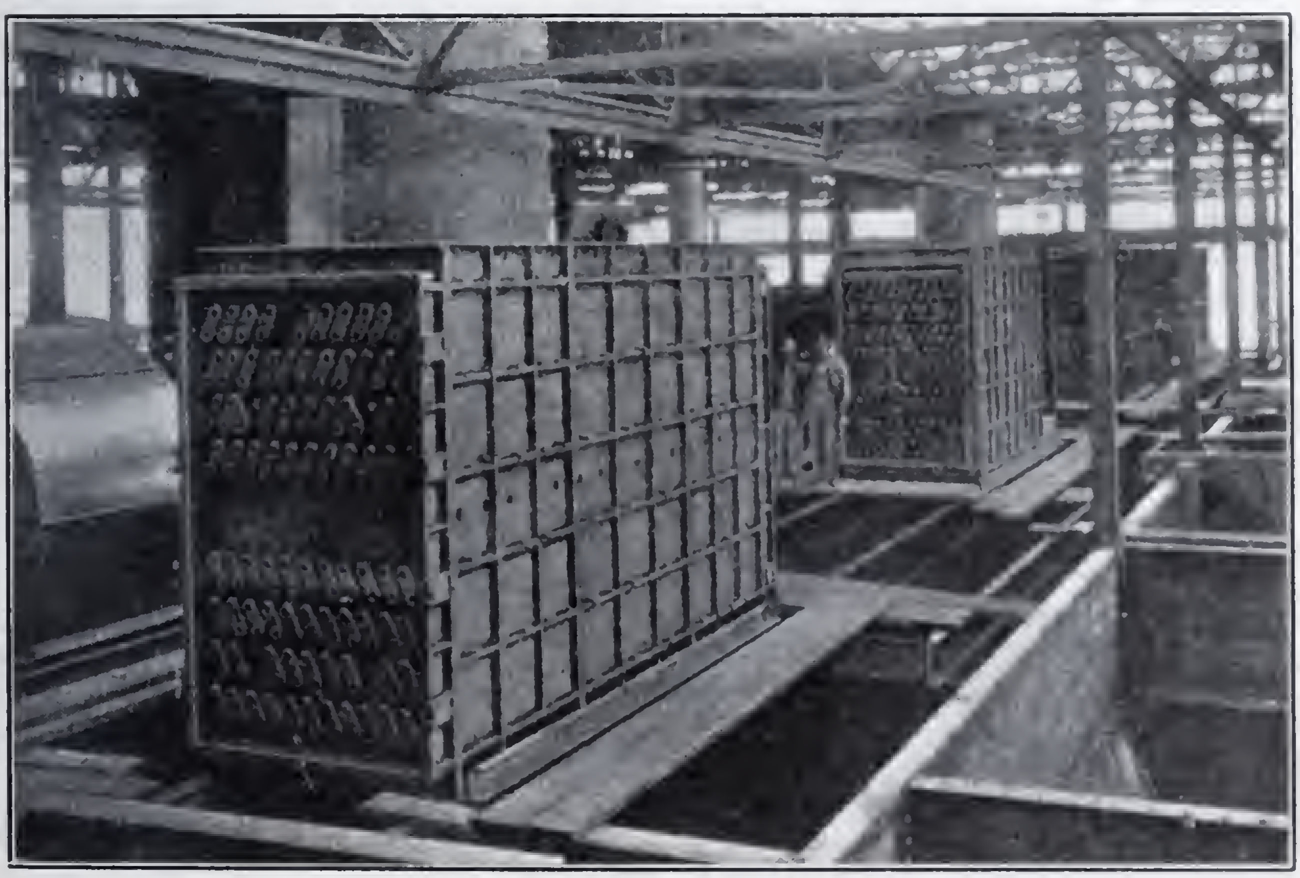

Fig. 3. Casing for Unit Steel-Tube Economizer.

struction which will stay tight under high suction pressures in spite of distortion strains imposed by heating and cooling of the casing over a wide range of temperature. Fig. 3 shows the construction of a flanged, cast-iron economizer casing.

Velocity of Water. Water should flow through the economizer in a direction opposite to that of the gas and at a velocity high enough, even at the lowest ratings, to prevent recirculation within the economizer and insure the maximum mean temperature difference due to full counter-current flow of gas and water. Eliminating recirculation will also eliminate any increase in concentration in water passing through the economizer and therefore eliminate the necessity for blowing down economizers in regular operation.

Velocity of Gas. Increasing the velocity of gas will increase the rates of heat transfer, which is, of course, desirable. There is a limit to the extent to which it is profitable to increase gas velocities. This limit is the point beyond which the increased investment charges for motors or other driving equipment for induced-draft fans, and increased expenses for additional power to operate induced-draft fans exceed the cost of additional fuel saved due to higher rates of heat transfer made possible by increased draft loss through the economizer. The question is one on which there is considerable misunderstanding and some unsound prejudice against reasonable draft losses.

It is not generally realized how small an increase in water-temperature rise through the economizer will supply the heat required to generate power needed for a draft loss of one inch water-gage. In Fig. 4 this is shown for a typical case for gas temperatures of 500 and 300 degrees at the induced-draft fan, and for plant heat rates of 10,000 to 40,000 B.t.u. per kilowatt-hour at the switchboard. It will be noted that at 20,000 B.t.u. per kilowatt-hour, 2.4 degrees additional rise with gases at 500 degrees at the induced-draft fan, and 1.9 degrees additional rise with gases at 300 degrees will produce the additional power required for increasing draft loss one inch water-gage. In most cases, additional water temperature rise per inch of draft loss through the economizer will be in excess of these figures up to an economizer draft loss of two inch water-gage or more. The values in Fig. 4 are based on the following efficiencies—fan, 60 per cent.; elec-

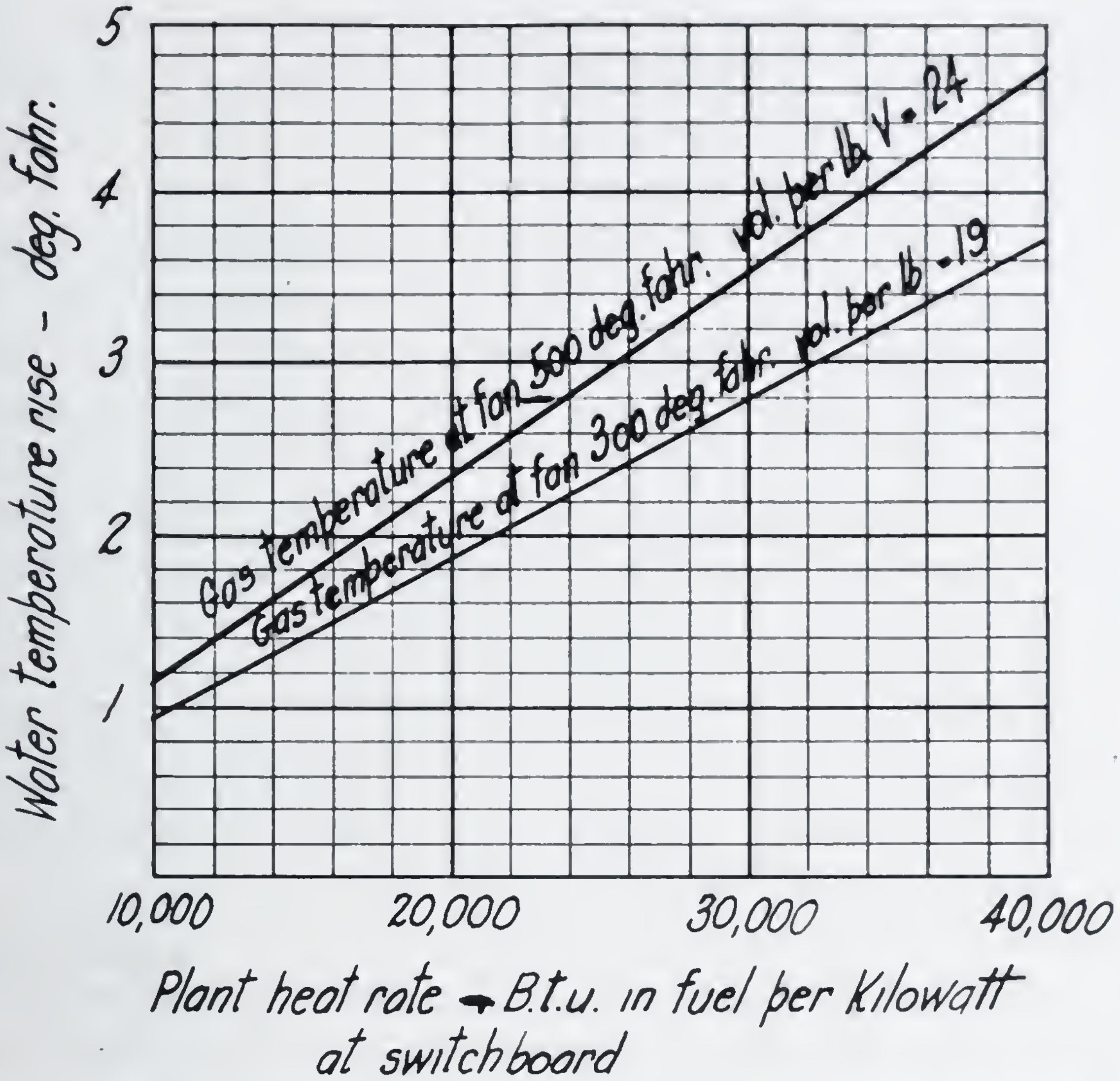

Fig. 4. Chart Showing Temperature Rise in Economizers for Power to Produce Draft of One Inch Water-Gage.

trical, 85 per cent.; overall boiler and economizer, 85 per cent.; and on 1.5 pounds of gas per pound of water in the economizer. This means that, within the limits indicated, the cost of fuel for additional power to handle it is less than the cost of additional fuel saved due to increased draft loss through the economizer.

Cleaning. Adequate soot-cleaning facilities should be provided, and it has been found that, with few exceptions, the most satisfactory

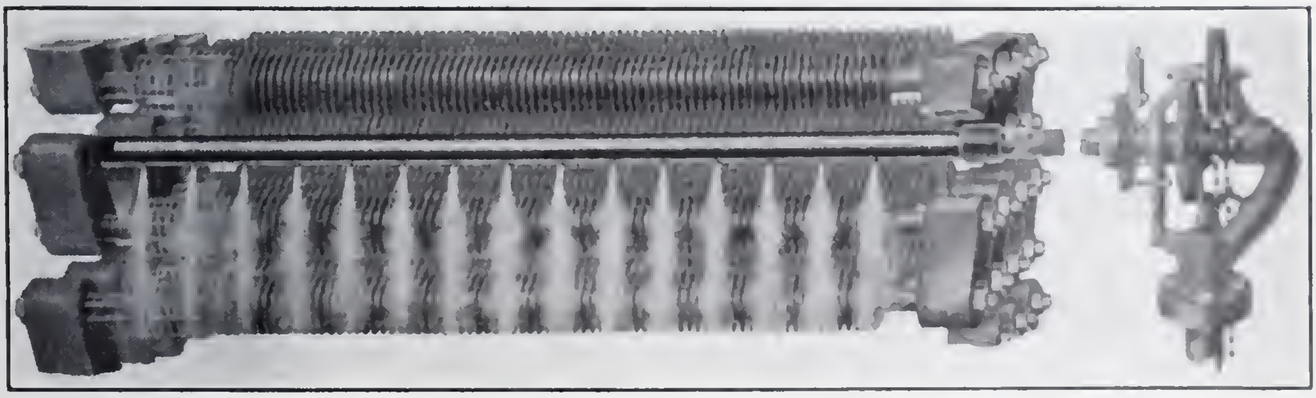

Fig. 5. Method of Cleaning Economizers by Means of Soot Blowers.

method of cleaning external surfaces is by means of soot blowers. Fig. 5 illustrates a method of doing this.

Internal Corrosion. Water to steel-tube economizers should be free from acids or other corrosive impurities. It is usually advisable to heat the feed-water to a temperature of 210 degrees before it enters the economizer. Under these conditions it is possible to reduce oxygen content to 0.2 per liter in open feed-water heaters. If slight alkalinity is maintained in water entering the economizer this is low enough to reduce corrosion to an amount that for all practical purposes will have no bearing on the life of economizer elements.

Extended Surface. At the present time, there are two principal types of counter-flow unit steel economizers—the plain-tube type and the extended-surface type. Both are designed for horizontal elements and vertical gas flow. In a typical plain-tube design, the elements are steel tubes of two inches outside diameter placed 3½ inches from center to center horizontally and about five inches vertically. With this spacing, the heating surface is 0.52 square foot per lineal foot of element and 4.3 square feet per cubic foot of space occupied by the elements.

In the Foster extended-surface type, the elements consist of steel tubes two inches in outside diameter on which gilled cast-iron rings are shrunk after being accurately machined to an inside diameter slightly less than the outside diameter of the tubes. In this type, the elements are spaced on 5½ inches from center to center horizonally and 5⅜ inches vertically. The heating surface is three square feet per lineal foot of element and 14.6 square feet per cubic foot of space occupied by the elements. The rate of heat transfer per square foot of heating surface in this type of element is about 85 per cent. of the rate of heat transfer in a bare-tube element. This difference is due, first, to increased thickness of metal and to joints between rings and tubes through which heat must flow from gas to water, and, second, to the fact that with increased surface per lineal foot in contact with the gas, the temperature of the metal is higher and the difference between the temperature of the gas and that of the metal is less than with the plain-tube element. The rate of transfer per square foot of extended surface based on the difference in temperature between gas and water

will therefore be slightly less, but the net transfer per lineal foot will still be considerably greater than with a plain-tube element.

Five years ago, in discussion of a paper on power-plant design before your Society,* one of the speakers called attention to the fact that there were then in service but two Foster economizers of the extended-surface type, and stated that under these conditions it did not seem necessary to comment further except to say that this type of machine was still in the experimental stage, and that, as with any other piece of apparatus of this character, its success must rest upon the return received from money invested. Over 350 Foster economizers have now been installed in connection with a total of 400,000 boiler horse-power, and all development problems have been satisfactorily solved.

Fig. 6 shows Foster economizers at the Lake Shore plant of the Cleveland Electric Illuminating Company.

The arguments ordinarily advanced in favor of the use of air heaters instead of economizers, are (1) that greater reduction of flue-gas temperatures is possible on account of the relatively high temperature of water entering the economizer, and the relatively low temperature of air entering the air heaters; (2) that combustion conditions are improved by the use of hot air, and that there are allied advantages, which, although they can not be measured directly, do improve efficiency and in some cases capacity, and should be considered in addition to advantages resulting directly from the return of heat to the furnace as determined by the temperature and weight of hot air entering the furnace.

The first of these arguments is obviously true. There is some question as to the comparative effect on efficiency and capacity of waste heat as recovered in an economizer and in an air heater. This question will be referred to later. The improvement of combustion conditions, due to air heating, is in many cases a matter of opinion and a matter on which opinions differ. With blast-furnace gas, high-temperature air heating is unquestionably well worth while. With some other fuels, moderate air heating to 250 or 300 degrees will improve combustion conditions. With other fuels, air heating will increase rather than diminish furnace operating difficulties; but only under very special conditions will combustion be improved by heating air above 300

*Proceedings, v. 38, p. 166.

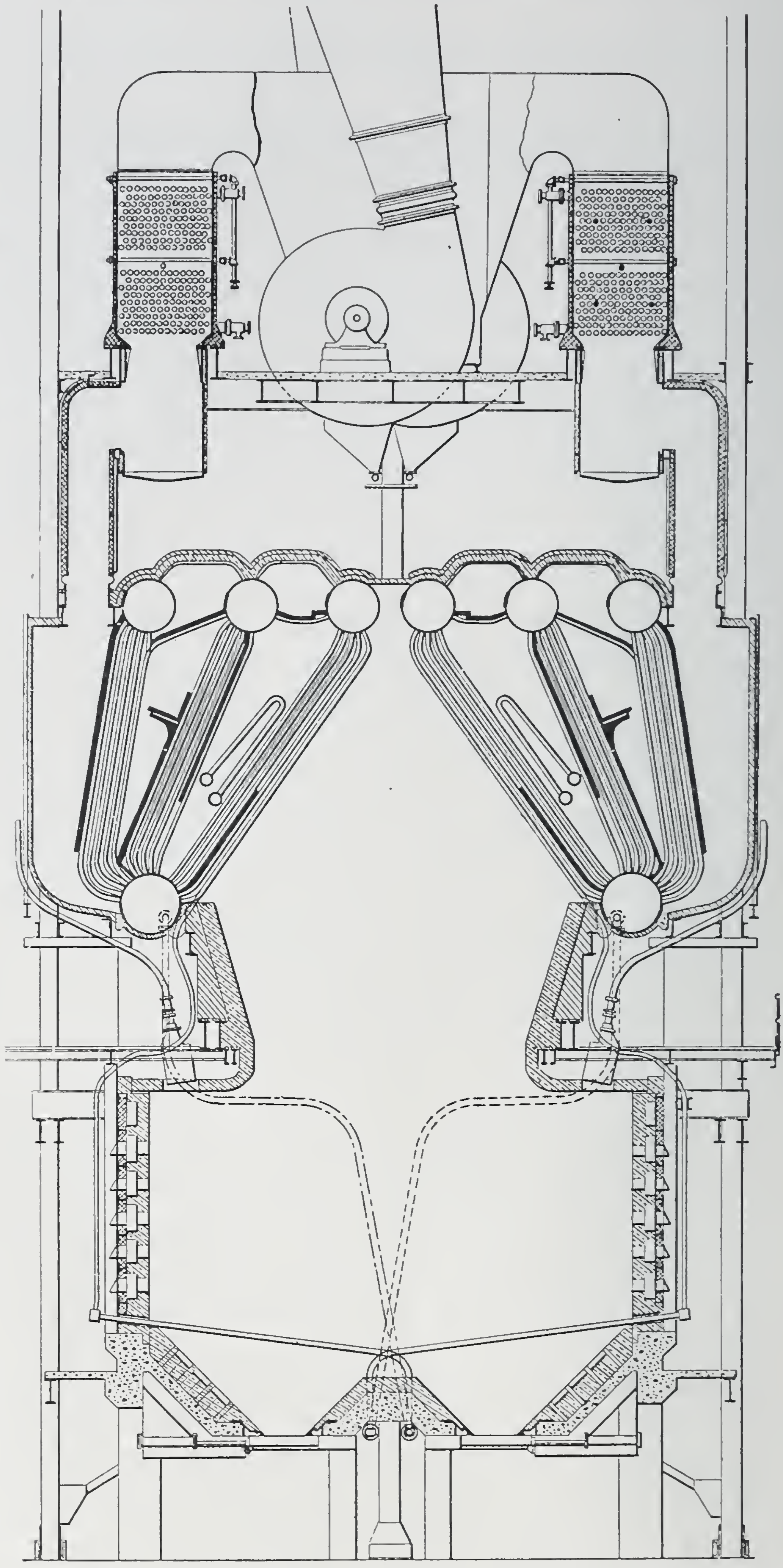

Fig. 6. Foster Economizer Installation with Stirling Boilers of 3060 Horse-Power.

degrees. In many cases, good engineering dictates the use of both economizers and air heaters. In others, economizers only, but only rarely are air heaters alone to be preferred.

An air heater is a device in which heat in flue-gases leaving the boiler is utilized to reduce the amount of heat that must be supplied in fuel to the furnace per pound of steam generated. To accomplish this heat absorbed from the flue-gases is added to the air for combustion as it passes through the air heater before entering the furnace. The return of this heat to the furnace does not affect the amount of work that must be done in the boiler, nor the total heat partly in fuel and partly in hot air that must be supplied to the furnace per pound of steam generated. For the same amount of heat liberated in the furnace, air heating will not result in any increase of capacity; but, for the same amount of steam generated, it will save fuel in the same proportion that the heat returned to the furnace in hot air is to the total heat supplied.

In many plants the capacity of boiler units is limited by the amount of heat that can be liberated in furnaces without trouble on account of clinker or slag, or prohibitive wear and tear on refractories. In such cases, air heating can not increase the capacity of boiler units which is fixed by the amount of heat that can safely be liberated in furnaces. The use of economizers, however, as previously explained, would provide additional capacity at the same rate of heat liberation in the furnace. Wherever peak-load capacities are limited by furnace conditions, boiler economizer units have higher capacities than boiler air preheater units, and should be credited accordingly when considering the size or number of units that should be installed to provide a desired peak-load capaicty.

At the high ratings now more and more generally required, the gases from boilers can not be cooled entirely in air heaters without very high temperatures, thus increasing the cost of insulating and the size of air flues, which at best are a troublesome and objectionable feature of any air-heater installation as compared with economizer installations in which large and awkward hot-air flues are replaced by feed-water piping from the economizer to the boiler. In large units the cost of Foster economizers and extra piping is ordinarily less than the cost of Foster air heaters and flues to do the same work.

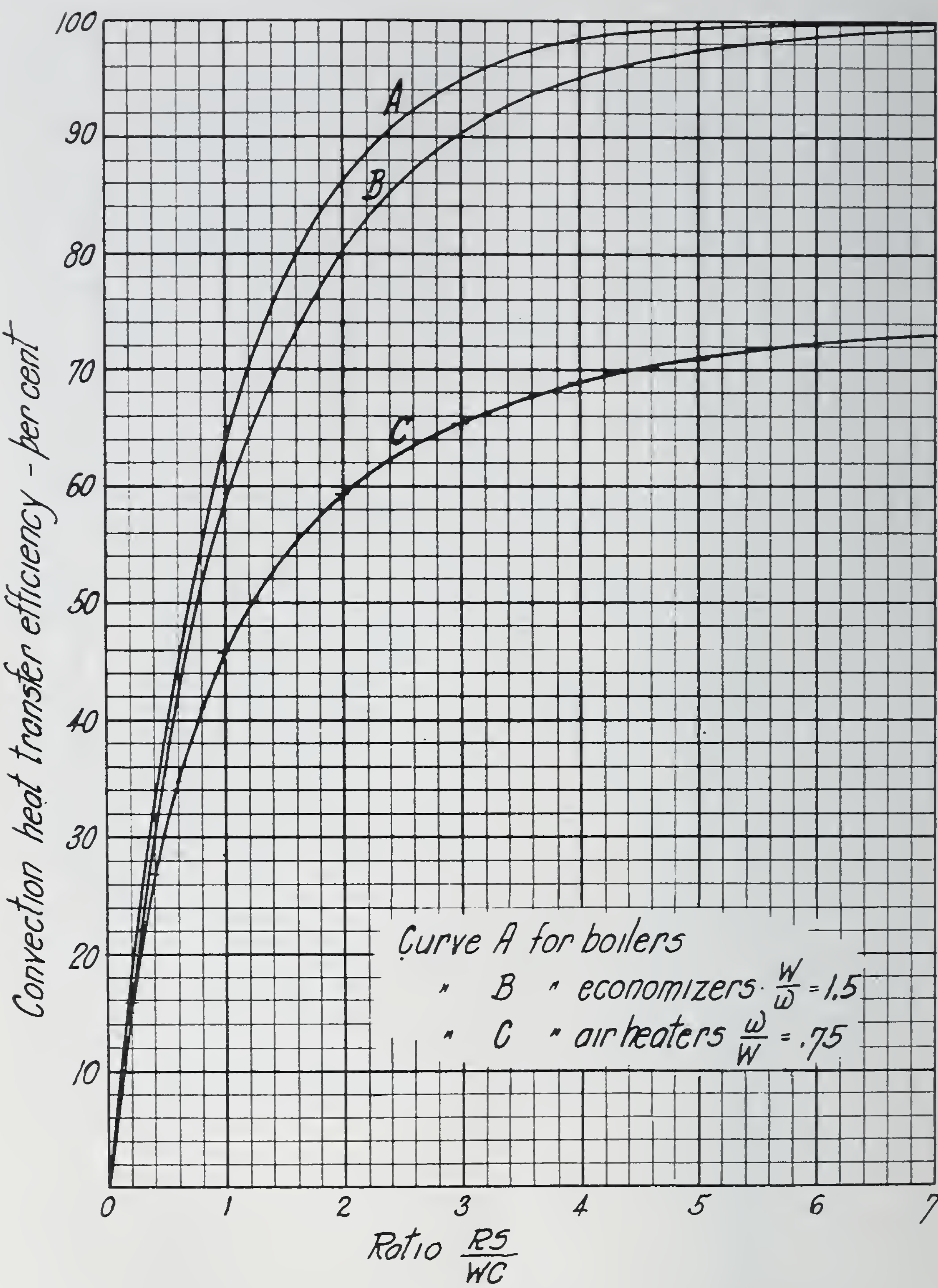

Fig. 7. Curve Sheet Showing Convection Heat-Transfer Efficiencies in Boilers, Air Heaters, and Economizers.

The curves in Fig. 7 have been plotted to show typical heat-transfer efficiencies in boilers, air heaters, and economizers. It has been assumed that the weight of air is 75 per cent. of the weight of gas passing through the air heater, and the weight of gas 150 per cent.

of the weight of water passing through the economizer. These ratios are typical of good operating practice. In general, it will be noted that the efficiency of heat transfer is practically the same in boilers as in economizers; but, when more than 35 per cent. of the heat available is absorbed in air heaters, the efficiency of transfer falls off sharply in comparison with boilers or economizers. This means that in economizers of all sizes, full advantage can be taken of the heat heads available, but in large air heaters the advantage of large temperature differences between incoming gas and incoming air is largely offset by decreasing heat-absorption efficiency as the size of air heaters is increased. The reason for this is that, in economizers, water temperatures increase only about one-third as fast as gas temperatures decrease; but, in air heaters, air temperatures increase about one-third more rapidly than gas temperatures decrease. Mean temperature differences, therefore, fall off rapidly as the amount of heat added to air is increased.

Symbols used in Fig. 7 and Table I are as follows:

W = Weight of gas in pounds per hour.
w = Weight of water in pounds per hour.
T_1 = Inlet temperature of gas in degrees F.
T_2 = Outlet temperature of gas in degrees F.
t = Temperature in degrees F. of steam and water in boiler.
t_1 = Outlet temperature in degrees F. of water in economizer or air in heater.
t_2 = Inlet temperature in degrees F. of water in economizer or air in heater.
R = Rate of heat transfer in B.t.u. per hour per square foot per degree mean temperature difference.
S = Heating surface in square feet.
C = Specific heat of gas in B.t.u. per pound per degree F.
c = Specific heat in B.t.u. per pound per degree F. of water in economizer or air in air heater.

Referring further to Fig. 7, if gases in a boiler are cooled by convection from 2000 to 550 degrees, with steam and water temperature of 400 degrees, the absorption efficiency is 0.91, and the value $\frac{RS}{WC}$ required for this efficiency is 2.40.

If the value $\frac{RS}{WC}$ is reduced 23 per cent. (from 2.40 to 1.85), the heat absorption efficiency will be 0.84 and the exit gas temperature 650 degrees. In order to reduce $\frac{RS}{WC}$ 23 per cent., the boiler-heating surface would have to be reduced more than 23 per cent. because in this term the value for S is the boiler-heating surface plus the boiler-heating surface equivalent for the superheater. The value of this equivalent will depend (1) on the amount of superheat, as this will determine the range through which gases must be cooled by the superheater; (2) on the location of the superheater, as this will determine the amount of boiler-heating surface that would be required for such cooling. A superheater near the furnace will be smaller and will have a smaller boiler-heating surface equivalent than a superheater farther back in the boiler, delivering the same superheat. This is a factor which often is not (but which should be) given proper consideration when determining the size of boiler to be used in any particular case. If then, in the case assumed, the boiler-heating surface is reduced about 25 per cent., the temperature of exit gases will be increased from 550 to 650 degrees.

Performance values for certain economizers and air heaters that might be installed in place of the boiler-heating surface omitted are tabulated in Table I.

TABLE I. PERFORMANCE OF ECONOMIZERS AND AIR HEATERS

1	2	3	4	5	6	7	8	9
Line	Surface	$\frac{RS}{WC}$	Ratio	$\frac{T_1—T_2}{T_1—t_2}$	t_2	$T_1—t_2$	$T_1—T_2$	T_2
1	Economizer	1.25	0.675	0.66	350	300	198	452
2	Economizer	1.25	0.675	0.66	300	350	231	419
3	Economizer	1.25	0.675	0.66	250	400	264	386
4	Economizer	1.25	0.675	0.66	200	450	297	353
5	Economizer	2.00	1.08	0.81	350	300	243	407
6	Economizer	2.00	1.08	0.81	300	350	283	367
7	Economizer	2.00	1.08	0.81	250	400	324	326
8	Economizer	2.00	1.08	0.81	200	450	364	286
9	Air heater	1.25	0.675	0.50	70	580	290	360
10	Air heater	2.50	1.35	0.63	70	580	366	284
11	Air heater	3.75	2.03	0.68	70	580	394	256

$T_1 = 650$. Ratios of economizer to boiler-heating surface will be slightly less than the ratios in column 4. Ratios of air heater to boiler-heating surface

will be about double the ratios in column 4. For a boiler without economizer or air heater, $\frac{RS}{WC} = 2.40$, and $T_1 = 550$. For a boiler with any of the above economizers or air heaters, $\frac{RS}{WC} = 1.85$, and $T_1 = 650$. Ratio $\frac{1.85}{2.40} = 0.77$.

These performance figures show that with air at 70 degrees and the boiler as described above with exit gases at 650 degrees:

1. A 60-65 per cent. economizer will cool gases to 386 degrees with 250-degree feed-water; and to 353 degrees with 200-degree feed-water, and 135 per cent. air heater will cool gases to 360 degrees.

2. A 100 per cent. economizer will cool gases to 326 degrees with 250-degree feed-water; and to 286 degrees with 200-degree feed-water, and 270 per cent. air heater will cool gases to 284 degrees.

3. A 406 per cent. air heater would be required to cool gases to 256 degrees.

4. Increasing the size of the air heater three times (from 135 to 406 per cent.), will increase work done in the air heater only 35 per cent.

These typical examples of comparative air-heater and economizer performances indicate:

1. That in all cases a careful analysis is essential to a correct determination of the amounts of air-heater or economizer surface that should be installed to meet any given operating conditions or requirements.

2. That, as the size is increased, the rate of heat transfer in air heaters falls off so rapidly that a very large air-heater installation can rarely be justified under normal operating conditions.

DISCUSSION

R. E. BUTLER:* I have certainly enjoyed hearing this paper, and in general agree with what the speaker has said. It has been very interesting and is written in a way that illustrates the subject very well.

One point Mr. Keenan has brought out which I think is a good one is that air heaters are new, and in their enthusiasm over a new thing people sometimes lose sight of some of the advantages of older apparatus such as water economizers.

*Engineer, Babcock & Wilcox Co., Pittsburgh.

There is somewhat of a tendency along this line to-day—to install air heaters alone in connection with boilers and possibly overlook the advantages of water economizers. The selection of one or the other depends upon conditions in the plant, and in some cases a combination of both works out to best advantage. In some cases, for instance, where using low-grade fuels, such as blast-furnace gas, there seems to be every advantage for the air heater in preference to the water economizer, although in many cases where blast-furnace gas is fired, the best lay-out may be a combination of water economizer and air heater. When you get to the burning of high-grade fuels this, in combination with other circumstances, may make water economizers decidedly the better apparatus to install for the best return on the investment. One of the distinctive advantages of the air heater is its lower cost and lower maintenance.

The figures Mr. Keenan has given on heat-transfer rates check with my own ideas; that is, that the heat-transfer rate in water economizers is usually a little better than twice that of the air heater. For this reason, to produce the same results, appreciably less surface might be installed in the water economizer as compared with the air heater, and this lesser amount of surface in the economizer tends to offset the cheaper cost per square foot of surface of the air heater. This results, in some cases, in the water economizer showing a better return on the investment than the air heater.

In the large central power-stations where they are now going into turbine stage bleeding and high feed-water temperatures, the air preheater will usually show the best return. Nevertheless, even here there is a field for the combination of air heater and water economizer.

It would appear that the so-called steaming-type economizer is going to come into wider use. I know of several recent installations of steaming economizers and they appear to be very satisfactory. It is probable, however, that they will be used only in the larger central power-stations, and to what extent remains to be seen. With the older cast-iron economizer, it was necessary to avoid any steaming in the economizer to avoid danger of explosions, but with the wrought-steel type and proper design this danger is overcome.

I was much interested in what Mr. Keenan said about corrosion in a steel economizer. His figures bear out our experience, particularly as regards corrosion from oxygen. This is something we are all very

much interested in, in this territory, because nearly all the waters in industrial use here contain oxygen. The recommendations he has given for heating the feed water up to 210 degrees F. in an open heater and thereby limiting the oxygen content to about 0.2 cubic centimeter per liter, which practically eliminates corrosion troubles, has also been our experience.

Very recently a new plant in this territory had trouble from oxygen corrosion in the boilers. The feed-water was heated up to about 180 degrees F. in an open heater, and soon after the new plant was started up corrosion was observed in the rear part of the boiler. It was found that with water at this temperature the oxygen content would range between 2 and 3 cubic centimeters per liter. After the corrosion was observed, they arranged to heat their feed-water up to 210 degrees F. and maintain it at this temperature. Under these conditions, they found the oxygen content was only 0.18 cubic centimeter per liter. As soon as the feed-water was maintained at 210 degrees F. in the open heater, corrosion ceased.

R. S. BAYNTUN:* I have been very much interested in the paper and I do not wish to dispute the figures given by an expert on the subject, but I think that a little more favorable consideration might have been given to the question of air heating. In connection with the figures quoted on heat transfer, you must remember that the body of the preheater is very much cheaper than the economizer. You must not lose sight of that. I think it has a very important bearing on the cost.

Then Mr. Keenan made the statement that it is not justifiable to put in an economizer without an air heater. I think it is very often good practice to have an air heater without an economizer, on this ground. Where you have feed-water that can be favorably heated by stage bleeding or an equivalent, such as in industrial plants using evaporators, where you can absorb the heat in the vapors from the evaporators in your boiler feed-water, that gives a very good and economic method of obtaining power as well as heating the feed; and, in making a comparison of air heater and economizer systems, we should take into account not only the water but also the power, because where you have stage heating you have power generated. You

*Rust Engineering Co., Pittsburgh.

heat your feed-water by the use of steam and you have to extract the heat from the flue-gases in an air preheater or not at all. I think that considering matters in the light of overall efficiency gives a more equitable means of comparison between the two systems.

I can give you some figures on an air preheater installation in which the boilers operated at around 200 per cent. rating with air preheaters, evaporators, and stage heating; the flue-gas outlet temperature in the boiler was 240 degrees, which is a very low figure; feed-water entering the boiler was 350 degrees; and additional power of about 10 per cent. of the total output was generated by that method of heating the feed-water. I think that this figure will be very hard to equal by a boiler and economizer arrangement alone.

H. M. Olson:* I do not see why you should not have scale in the economizer, in many cases, if there are scale-forming salts in the feed-water. Most of the waters around here have scale-forming salts in solution, and it is my opinion that these waters will deposit scale in economizers as well as in boilers, the amount depending on the composition of the water and the pressure and temperature existing in the economizer. "Zeolite" softeners will eliminate this scale, and other methods of treatment such as the lime and soda-ash process will greatly reduce it.

P. Nicholls:† It seems to me that the author has possibly stopped a little short in the consideration of the functions of an air heater, and perhaps has not given a quite fair comparison between air heaters and economizers. What is the object of air heating; is it not more than merely heat transfer? The economizer can be considered as an extension of the boiler-heating surface, whereas an air heater may save fuel cost by better combustion, and investment in furnace construction or size by earlier combustion. It is granted that the experimental evidence on these two factors is not very conclusive at present, but is it not possible that inclusion of the gain, by being able to use cheaper fuel or due to construction cost, may enable air heating to appear more favorable?

*District Manager, Permutit Co., Pittsburgh.
†Heat Transmission Engineer, Pittsburgh Experiment Station, U. S. Bureau of Mines.

WALTER F. KEENAN, JR.: Mr. Nicholls has suggested extending the comparison between air heaters and economizers to take into account the fact that the object of air heating may be not only to recover a certain amount of heat but to make possible the burning of cheaper fuel. This also might apply to better burning of the same fuel, and where air heating does accomplish such results it is unquestionably desirable. On the other hand there can be such a thing as too much air heating not only from the standpoint of the relative inefficiency of large air heaters, but also because of such troubles as caking of coal, increased difficulty in handling clinker, and increased stoker or furnace maintenance if air temperatures with certain fuels are raised above some critical point. It is also doubtful how cheap a fuel it pays to burn. Considering the handling expense that must be paid into and out of the plant on the high ash content of many low-grade coals, and the increased operating and maintenance troubles and expense incident to the burning of such coals, I believe there are many instances where in the long run the effort to burn cheap fuel is hardly worth what it costs.

Mr. Nicholls also referred to the possibility of a saving in furnace construction due to air heating. This could be true only if the use of hot air made practicable a reduction in the size of furnace required. This would rarely be so, while in many instances air heating would necessitate water-cooled furnace construction that otherwise might not be necessary, and in such cases air heating would increase rather than reduce costs of furnace construction.

Mr. Bayntun states that more favorable consideration might have been given to air heaters, and in that connection I would like to say that I am not trying to discredit air heaters but only trying to present a paper on economizers. It would not be possible in the length of time that it seems proper to assign to such a paper to cover all possible cases that might come up on the question of air heaters versus economizers, and in the main I have based my discussion on conditions that exist in the ordinary power-plant. I readily agree that in a plant where they are using evaporators and get feed-water temperature of 350 degrees, and there is no waste heat around the plant that can heat the feed-water to that temperature, there is no place for economizers.

The case for turbine bleeding heaters has not been altogether proved. That is something like the thing Mr. Butler referred to

when he spoke of air heating as being a new fad, and perhaps this is a little over-emphasized. One stage of bleeding is good and two stages are good, and three stages may be good. I think there is some doubt about going to the fourth stage of turbine bleeding. The more stages of turbine bleeding you go to the less the return, and the cost goes up just the same.

Excluding plants where air heating is essential for satisfactory combustion of low-grade coal or other special fuel such as blast-furnace gas I believe that in the ordinary industrial plant, with feed-water temperatures not exceeding 250 degrees, economizers will show day in and day out a greater return on investment than air heaters. In central stations the extent to which economizers should be used depends on the extent to which it is in fact profitable to increase feed-water temperatures by stage bleeding of turbines. However, considering the high rating at which it is generally desired to operate steam-generating units in central stations, it would appear that in many such plants the ideal combination would be economizers and air heaters and moderate stage bleeding of turbines. I believe that there is a definite general trend in this direction.

In conclusion, I appreciate the honor of having been asked to speak before your Society. It has been a pleasure to be with you and I thank you for the courtesies extended to me by your Chairman and yourselves this evening.

DEVELOPMENTS IN HIGH-PRESSURE BOILERS*

By D. S. Jacobus†

The use of higher pressures in power-generating stations has come through the general trend of progress in the securing of higher and higher efficiencies. This movement has been coincident with the use of larger boilers, leading to a decrease in the cost of operation and more in keeping with the large power-plants of to-day. Larger furnaces have been developed to operate successfully at a high rate of heat of combustion per cubic foot of volume. All this has led to a far different sort of equipment from that employed a comparatively short time ago.

This country has taken the lead in the development of large, high-capacity, high-efficiency and high-pressure boiler units. It would have been impossible to accomplish this had it not been for the enterprise and co-operation of engineers and those having in charge the financial interests of power-plant construction. The Commonwealth Edison Company of Chicago installed the first large power-stations for a working steam pressure of 650 pounds, or over. The Boston Edison Company installed the first large boiler unit for 1200 pounds working pressure, to be followed by two additional units for the same plant for 1400 pounds working pressure. The Milwaukee Electric Railway & Light Company installed the largest boiler so far built for a working pressure of 1200 pounds or over. The engineers for these installations deserve every credit for their pioneer work and enterprise, as unforeseen difficulties might have led to a considerable amount of trouble. The high-pressure units were a success from the start, but this does not in any way detract from the credit due those who took the risk of first installing them.

In view of the large number of boilers built for 650 pounds working pressure, and over, that are now in successful operation in power-generating stations, this paper will be limited to boilers to be operated at this pressure, or over, and to certain features bearing on their development.

To secure the best economical results it is necessary to reheat the steam between the turbine stages when the pressure at the turbine

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†Advisory Engineer, Babcock & Wilcox Co., New York.

throttle reaches the neighborhood of 550 pounds per square inch. The reheaters used for this purpose will be described, as well as the economizers and air heaters used in connection with the boilers.

All of the boilers herein described were built in accordance with the "Boiler Code" of the American Society of Mechanical Engineers, with a factor of safety for the steam and water drums of at least 5, based on the minimum tensile strength of the specified range of the steel, and using the outer diameter of the drum in the computations. In addition to this, tests and computations were made to make sure of a factor of safety of 5 for the holding power of the expanded ends of the tubes, including all weight components.

Two forms of high-pressure boilers were described in a paper presented by the writer at the World Power Conference* held in London in July 1924. These boilers and the reheater superheater used in connection with one of them are shown in Fig. 1-3. These were the first boilers used in large power-plant practice in this country at as high a pressure as 650 pounds.

Fig. 1 is a side view of one of the boilers at the Crawford Avenue station of the Commonwealth Edison Company, Chicago. These boilers are 40 sections in width and are designed for a working pressure in the steam and water drums of 650 pounds gage and are operating to give a pressure at the turbine throttle of 550 pounds gage and a temperature of superheated steam of 725 degrees F. The lower bank of tubes in the boiler is made up of eight rows of 3¼-inch tubes 15 feet long, exposed for their full length above the furnace, and an upper bank of 17 rows of two-inch tubes. The two-inch tubes are staggered so as to provide diagonal lanes from the top to the bottom of the bank through which the tubes can be cleaned either by means of steam-blowers or by scraping when the boiler is down. The staggered arrangement of the tubes is also advantageous in increasing the heat transfer rate over what it would be with vertical lanes for the passage of gases between the tubes. The gases make a single pass over the lower bank of tubes, and two passes over the upper bank, after which they pass between nipples connecting the upper and lower parts of the downtake headers and flow downward over an economizer. The heating surface of each boiler is 16,615 square feet, and of each economizer 11,054 square feet, or 66.6 per cent. of the boiler

*Transactions of the First World Power Conference, 1924, v. 2, p. 1405-1440.

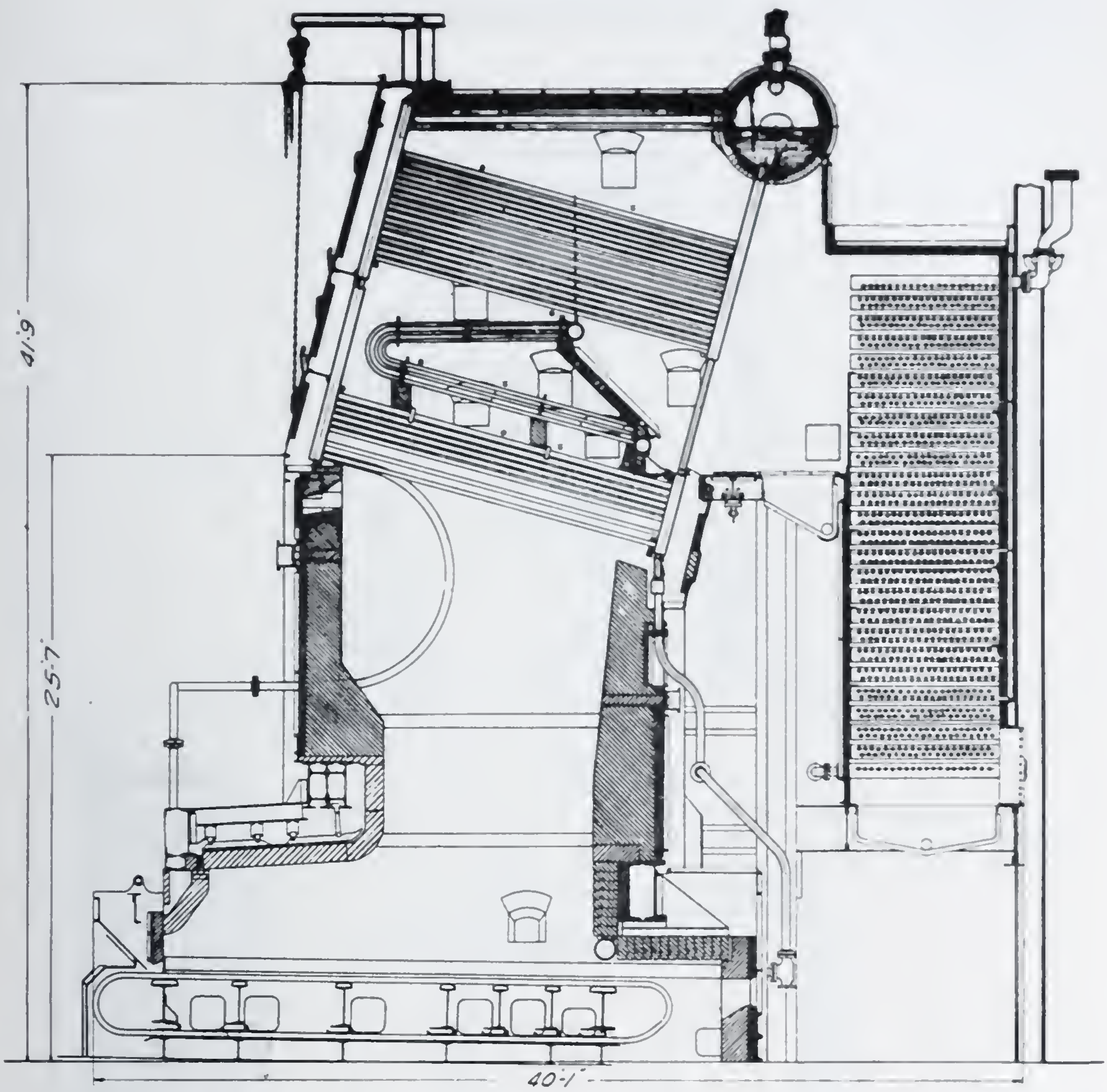

Fig. 1. Babcock & Wilcox Boiler Fired with Babcock & Wilcox Forced-Draft Chain-Grate Stoker, with Interdeck Superheater and Economizer.

heating surface. The boilers are fired with Babcock & Wilcox forced-blast chain-grate stokers 24 feet wide and 20 feet six inches long. The boilers were designed to evaporate 150,000 pounds of water per hour as a maximum, corresponding to nine pounds per hour per square foot of boiler heating surface. The temperature of the steam leaving the superheater at the maximum rating is 750 degrees F. The steam is reheated by passing it from the steam-turbine at 135 pounds per square inch absolute pressure to a resuperheater boiler unit of special design where its temperature is raised to 725 degrees F.

Fig. 2 is a side view of a reheater boiler used at the same plant as the boilers shown in Fig. 1. This is made up of a boiler and primary superheater over which the gases flow before they flow over

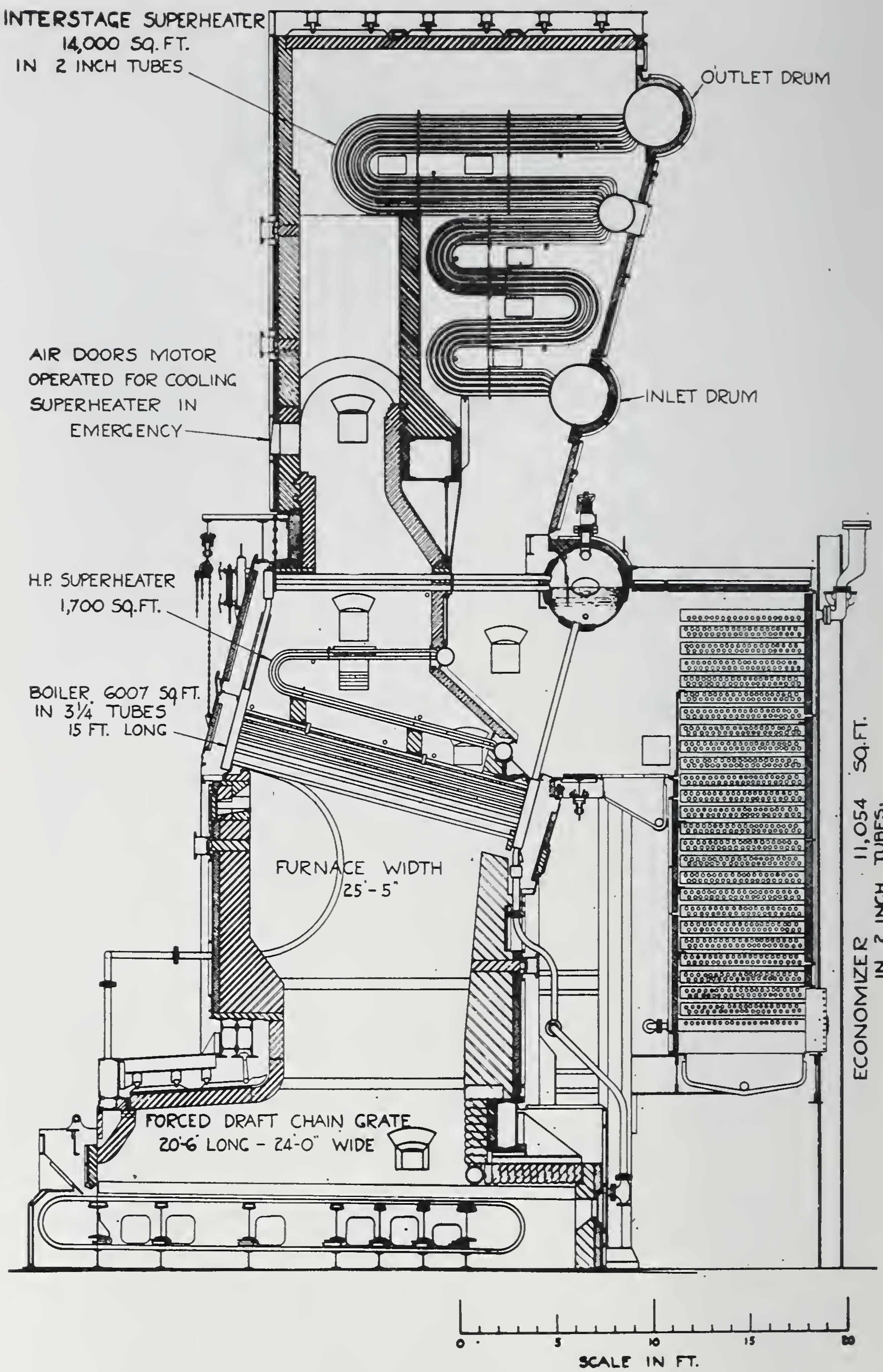

Fig. 2. Babcock & Wilcox Reheater Superheater Boiler Fired with Babcock & Wilcox Forced-Draft Chain-Grate Stoker, with Interdeck Primary Superheater and Economizer.

the tubes of the reheater superheater. The boiler, which is designed for a working pressure of 650 pounds gage, consists of a single bank of tubes placed directly over the furnace, this bank being of the same dimensions and arranged in the same way as the lower bank of the boiler shown in Fig. 1. The steam to be reheated enters the lowermost cross drum of the reheater and flows upward in parallel through the reheater tubes until it enters the upper drum, from which point it is led back to the steam-turbine. There are four boilers such as shown in Fig. 1 for each unit and a single reheater boiler, such as shown in Fig. 2. The water-heating surface of the reheater boiler is 6007 square feet. The surface of the interstage reheater superheater is 16,120 square feet, and is made up of two-inch tubes. The economizer used in connection with the reheater superheater boiler is of the same size as that used for the boilers shown in Fig. 1.

Fig. 3 is a side view of a Babcock & Wilcox boiler for 1200 pounds working pressure installed at the Edgar station of the Edison Electric Illuminating Company of Boston. The steam and water drum is of seamless forged steel construction 48 inches internal diameter and four inches thick. The boilers are 40 sections wide. The headers are of wrought steel. There is a lower bank of seven rows of two-inch tubes, and an upper bank of 15 rows of two-inch tubes, all of the tubes being 15 feet long and staggered in the same way as for the boilers for 650 pounds working pressure. The gases make a single pass over the lowermost bank of tubes, then flow over a primary superheater and over the uppermost ends of the upper bank of boiler tubes, thence over tubes of a reheater superheater, after which they make two passes over the uppermost bank of boiler tubes. The superheat obtained by the reheater superheater is regulated by means of a damper which is raised or lowered so as to cause more or less of the hot gases to flow over the tubes of the reheater superheater. The ends of the horizontal circulating tubes which connect the top of the uptake headers with the steam and water drum enter the drum in circumferential lines which are twice as far apart as the headers, thereby greatly increasing the efficiency of the ligaments over what it would be should the tubes enter the steam and water drum at the same distance apart as the headers. The minimum tensile strength of the specified range for the steel used for the drum is 55,000 pounds per square inch.

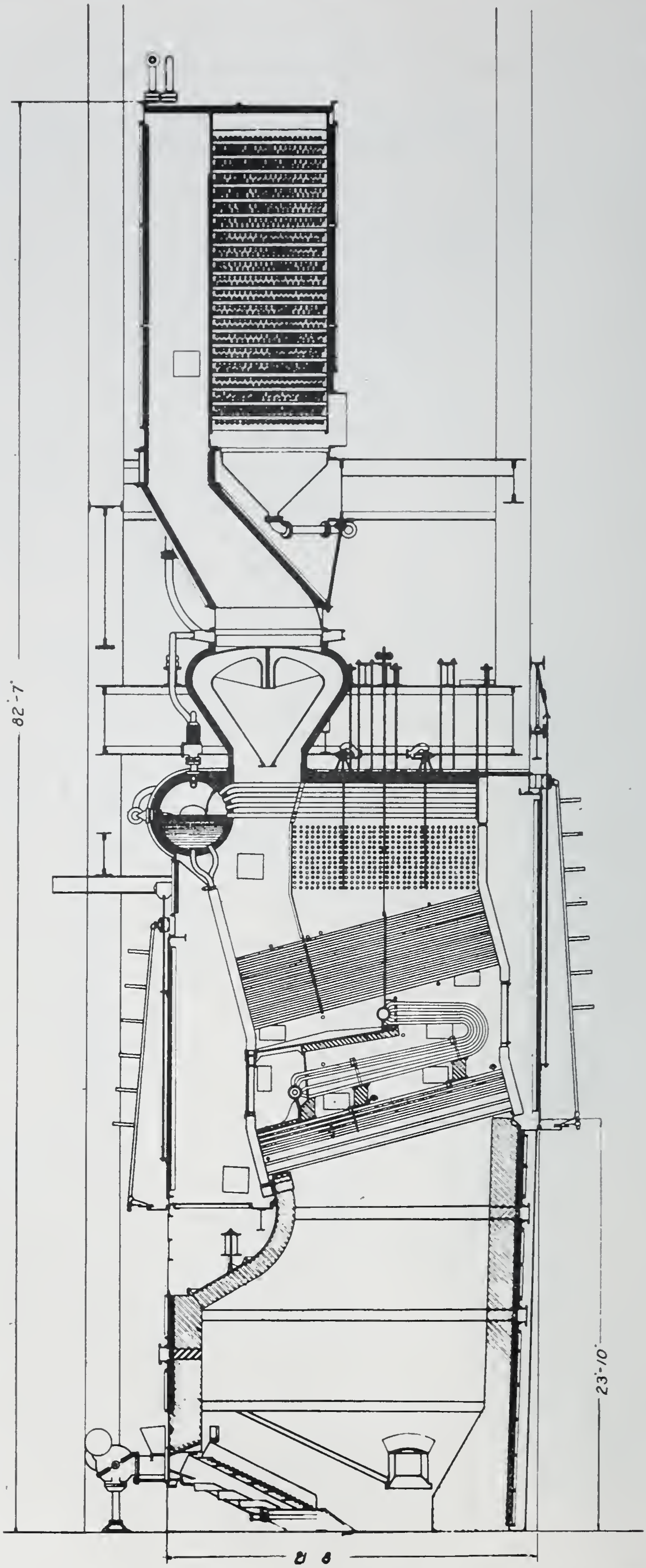

Fig. 3. Babcock & Wilcox Boiler Fired with Underfeed Stoker, with Inter-deck Primary Superheater, Reheater Superheater, Economizer

The economizer used in connection with the boiler is set above the boiler and is made up of two-inch seamless steel tubes connected to horizontal wrought-steel headers. The boxes are spaced apart to allow for the removal and replacement of the tubes from between the boxes. The heating surface of the boiler is 15,732 square feet, and of the economizer 11,110 square feet, or 70.6 per cent. of the boiler heating surface. The boiler was designed to evaporate 143,000 pounds of water per hour as a maximum, corresponding to 9.1 pounds per hour per square foot of boiler heating surface, and the superheater is designed to give a steam temperature of 710 degrees F. at this maximum capacity.

A Carty cinder catcher is used between the boiler and the economizer. This consists of a number of V-shaped gas passages between a number of elements having open ends and open bottoms. The cinders are thrown out of the gases by being projected downwardly from the narrow ends of the elements and by turning the gases under the sides of the elements into the upwardly flowing streams of gas which come between the elements.

Fig. 4 is a side view of two additional high-pressure Babcock & Wilcox boilers with forged steam and water drums which are being erected at the Edgar station. These boilers are built for a somewhat higher pressure than the boiler shown in Fig. 3, the working pressure being 1400 pounds per square inch. The inner diameter of the seamless forged steam and water drum is 48 inches, as in the first boiler, and steel of the same tensile strength is used. The thickness of the shell is 4⅝ inches. There is a lower bank of eight rows of 3¼-inch tubes 19 feet long connected to vertical headers, and an upper bank of 10 rows of two-inch tubes 17 feet long connected to inclined headers.

The economizers are smaller than in the first boilers and air heaters are used in addition to the economizers. The heating surface of each boiler is 15,093 square feet, and that of each economizer 5596 square feet, or 37.1 per cent. of the boiler heating surface; and of each air heater 33,032 square feet, or 218.9 per cent. of the boiler heating surface. It is proposed to evaporate 250,000 pounds of water per hour as a maximum, or 16.6 pounds per square foot of boiler heating surface per hour, and the superheater is designed to give a steam temperature of 729 degrees F. at this maximum capacity. One-third of

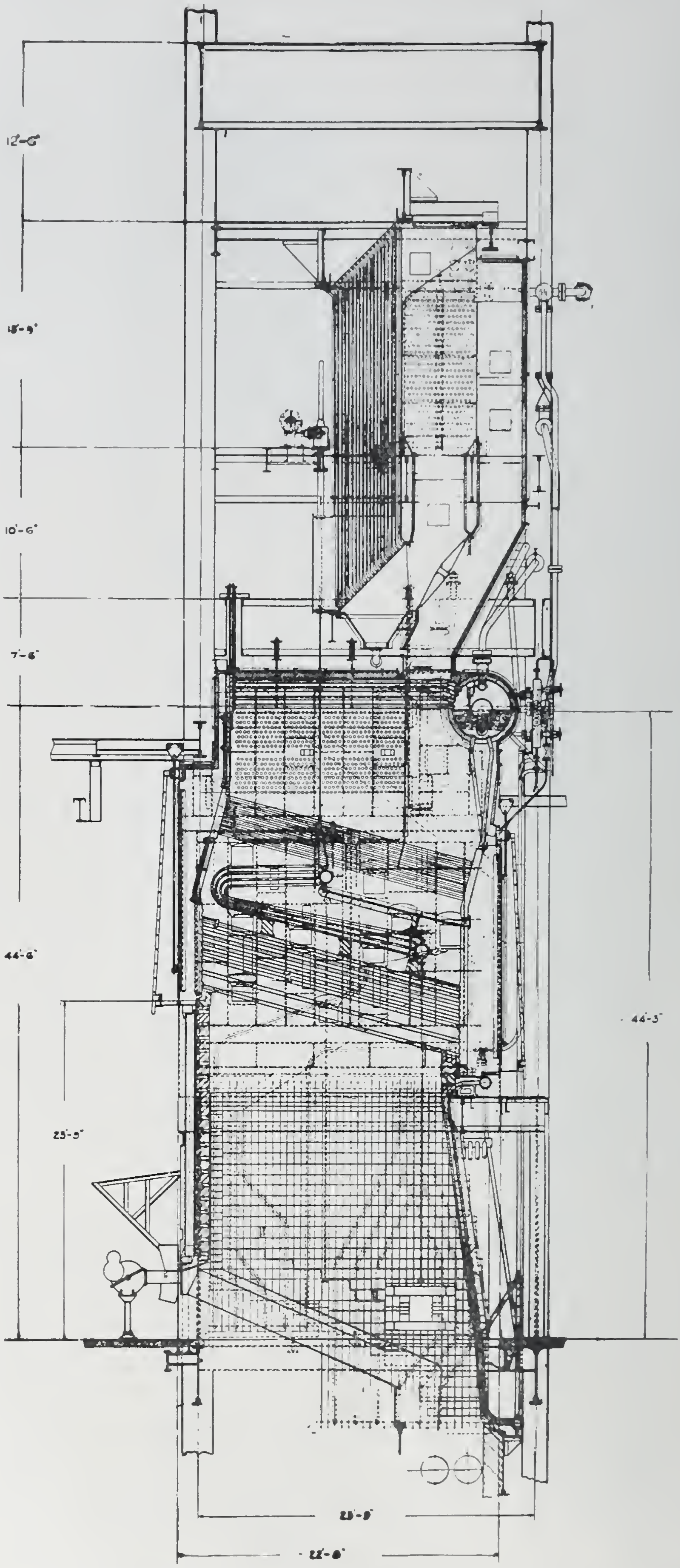

Fig. 4. Babcock & Wilcox Boiler Fired with Underfeed Stoker, with Inter-deck Primary Superheater, Reheater Superheater, Economizer and Air Heater.

the heating surface of the superheater is made up of "Enduro" steel tubes, which are more highly resistant to deterioration at high temperatures than are ordinary steel tubes. The steam makes three passes through the superheater, the hottest steam flowing through the section made up of the "Enduro" tubes. "Enduro" is a chromium steel having a carbon content of less than 0.1 per cent. and a chromium content of 16.5 to 18.5 per cent.

The reheater superheater is placed above the uppermost bank of boiler tubes and a damper is raised and lowered between the two

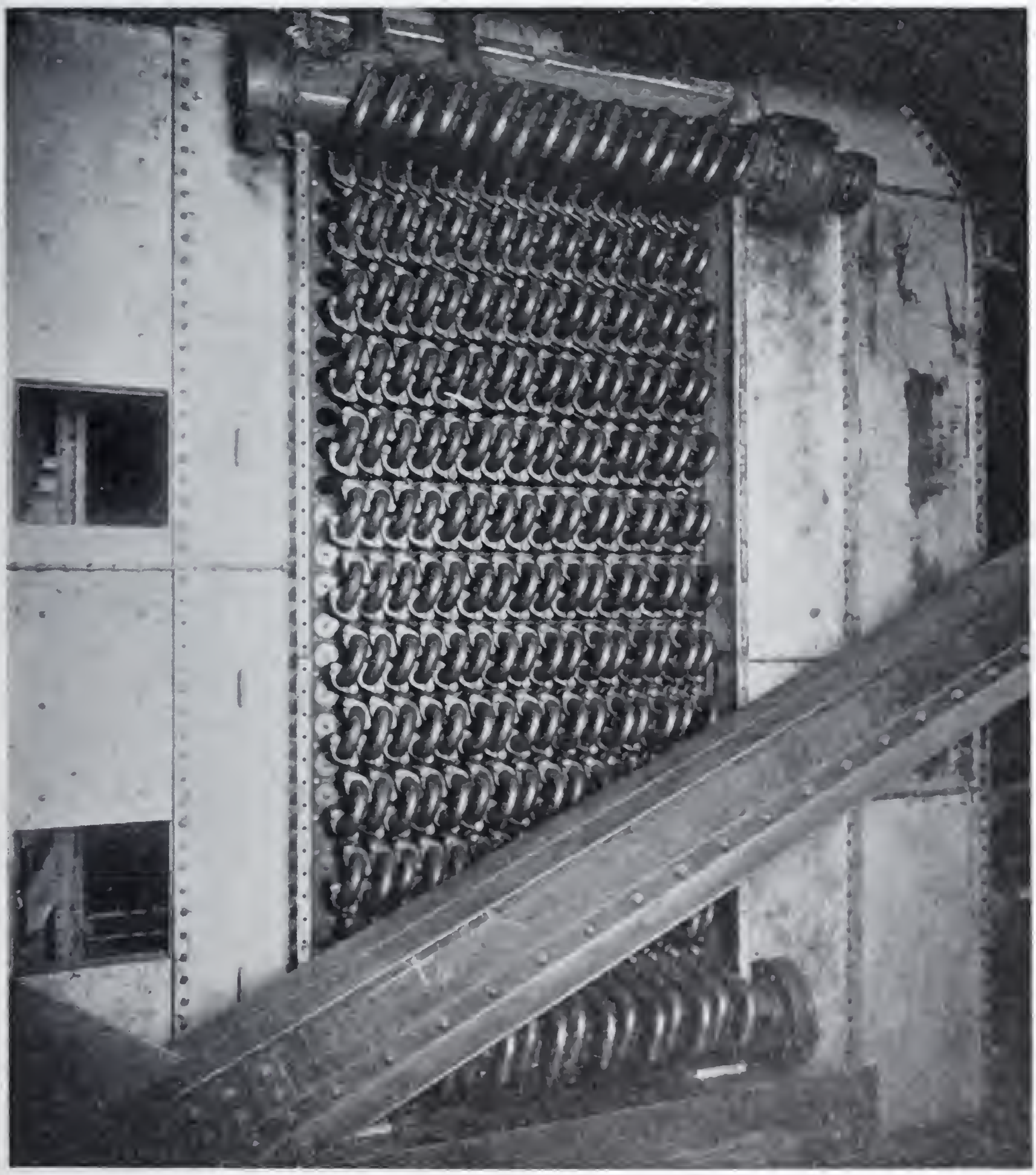

Fig. 5. One End of Return-Bend Wrought-Steel Economizer During Erection at Edgar Station of Edison Electric Illuminating Company, Boston.

banks to regulate the temperature to which the steam is reheated in the same way as for the 1200-pound boiler shown in Fig. 3. Two sets of U-tubes are used in the reheater, connected to two headers at each side of the setting, the steam flowing in parallel through the two parts of the reheater. This arrangement is somewhat different from that used in the boiler shown in Fig. 3, where the reheater tubes extended completely across the setting. The temperature of the superheated steam leaving the reheater is to be maintained at 750 degrees F. The boilers are fired with Taylor underfeed stokers. Bailey water-cooled furnace walls are used at the sides and rear of the furnace and a Bigelow hanging furnace wall is installed at the front of the furnace.

Fig. 5 is an end view of one of the return-bend wrought-steel economizers shown in Fig. 4 during erection at the Edgar station, and Fig. 6 is a side view of an economizer of the same type. Fig. 7 shows the arrangement of the return bends and end supports for the economizers. It will be noted that the economizers used in connection with the Edgar boilers are different from those used in the boilers previ-

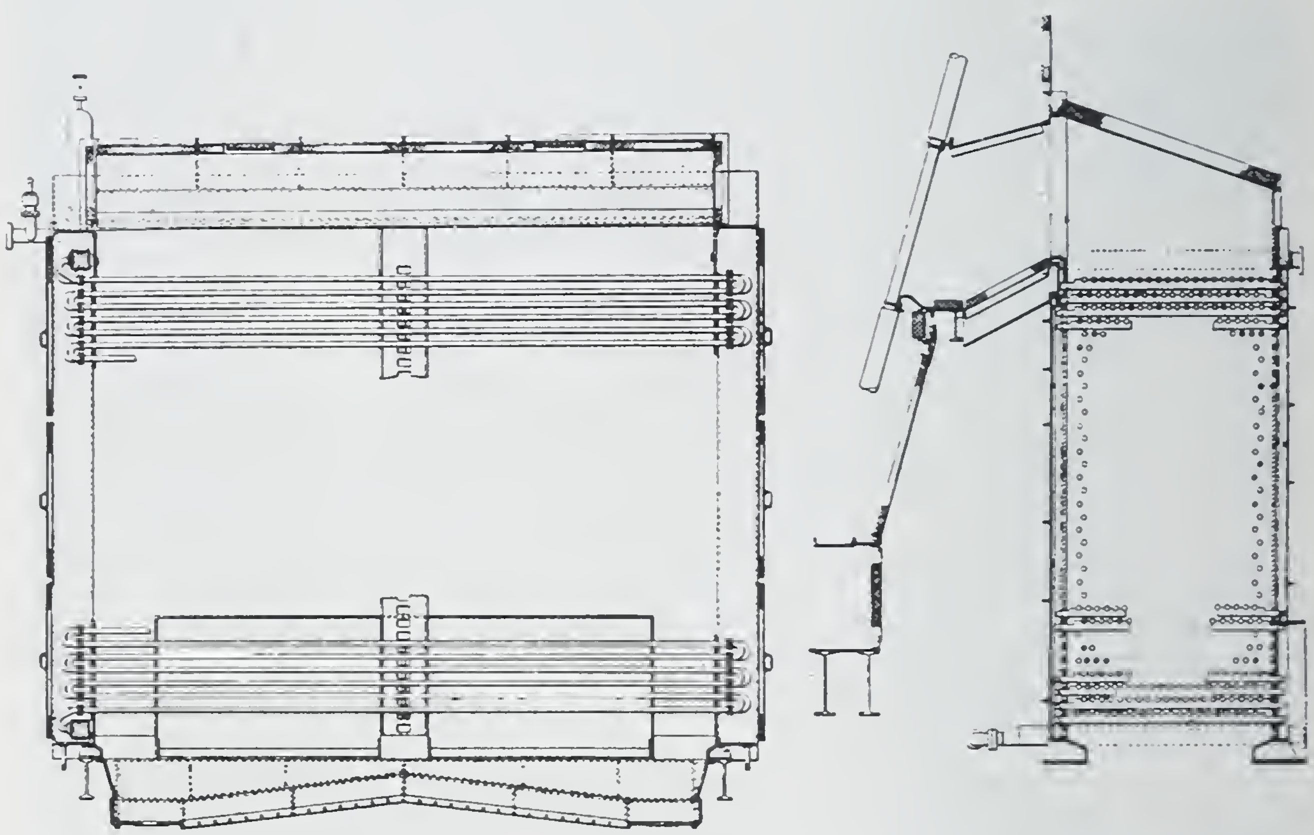

Fig. 6. Side and End View of Return-Bend Wrought-Steel Economizer.

ously described, in that they are made up of return bends with no horizontal headers except at the inlet and outlet of each economizer. These economizers were designed to meet the most severe conditions

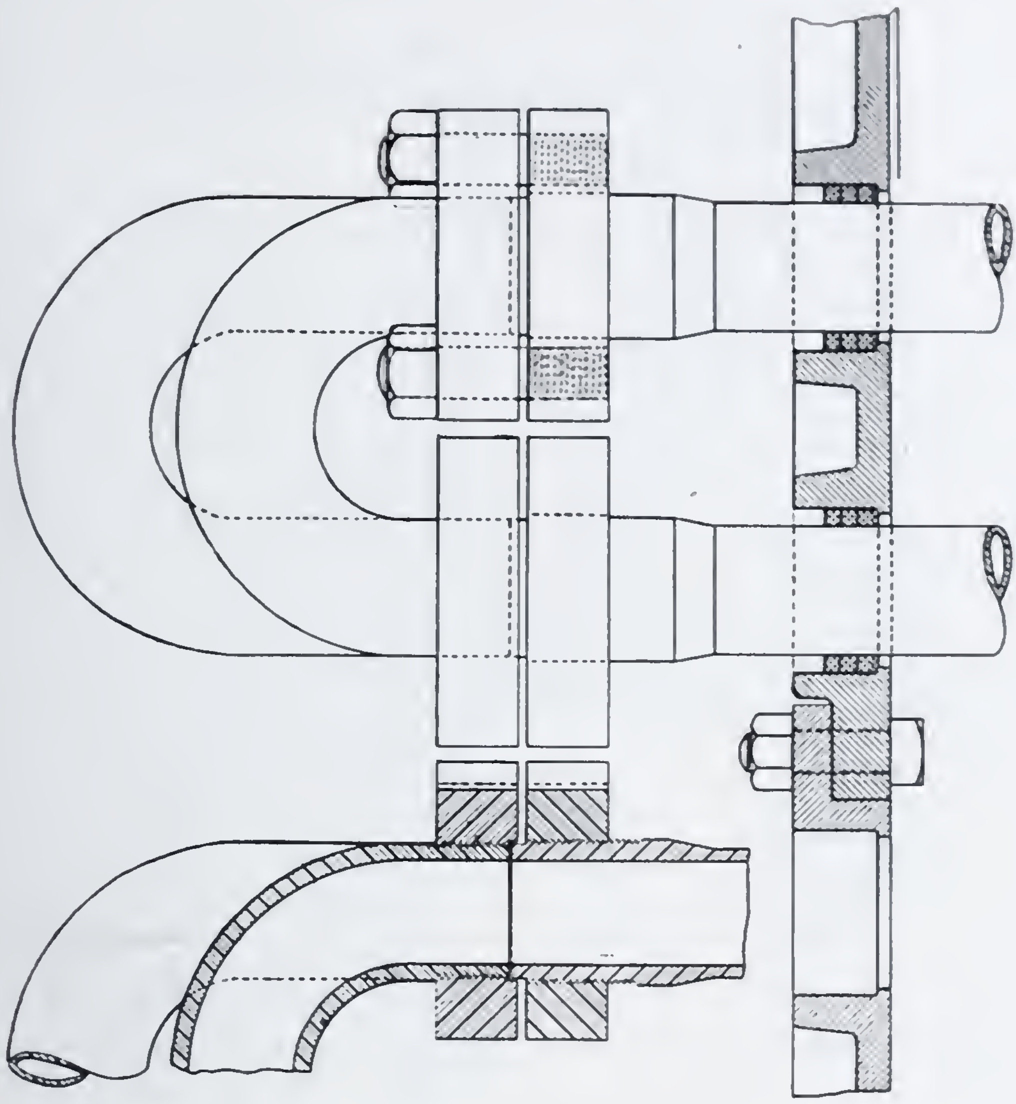

Fig. 7. Arrangement of Return Bends and Cast-Iron End Supports of Return-Bend Wrought-Steel Economizers.

in economizer practice and extensive tests have demonstrated that they withstand temperature strains, etc., that are more severe than can occur in any actual service. In common with the other economizers shown and described, the water enters the bottom of the economizer and is discharged at the top of the economizer and the hot gases flow downwardly over the economizer. By setting the economizers in this way there is no danger of a water-hammer should steam collect at the top of the economizer during a lay-over period and water be fed into the economizers. This setting also makes it easier to keep the economizer tubes clean on the outside as, should there be any collection of moisture or tar-like products from the flue-gases on the outside of the coolest tubes, the liquid will not fall downward over the tubes and increase the trouble due to the deposition of a sticky coating caused by soot from the flue-gases being deposited with the liquid. It further provides an economizer that will operate satisfactorily under steaming conditions in its regular service.

As shown in Fig. 6, the economizer tubes are supported at their middle points by pairs of steel bars which also hold the tubes in alinement.

The way in which the return bends are attached to the ends of the economizer tubes is shown in Fig. 7. The bends are made of seamless steel tubing somewhat thicker than the metal in the straight part of the economizer tubes. The ends of the bends are turned, faced, threaded, and fitted with flanges, as shown. The ends are counterbored and faced, and a thin gasket is placed between the machined faces. The tube supports at the ends are of cast-iron with a multiple system of bosses through which the tubes pass; each of the holes through the bosses has a shoulder at the inner end. After a tube has been set in place, a thin split ring of soft steel is passed over the tube and pushed into the counterbore back to the shoulder. This ring serves to center the tube and, in conjunction with packing, to close the holes through the bosses. The construction allows for longitudinal expansion or contraction of the economizer tubes and at the same time provides gas-tight and water-tight joints, the latter feature being of particular importance if the economizers are to be cleaned externally by washing.

Fig. 8 is a side view of a Stirling boiler constructed for 1390 pounds working pressure at the Lakeside plant of the Milwaukee Electric Railway & Light Company. The boiler is of a special Stirling design with two steam and water drums above, and a mud drum below. The drums are of seamless forged steel construction five inches thick and 40 inches inside diameter, the steam and water drums being 41 feet, 6 inches long, and the mud drum 40 feet long. The minimum tensile strength of the specified range for the steel used for the drum is 75,000 pounds per square inch. The heating surface of the boiler is 28,532 square feet. This boiler is set above a water-cooled furnace for burning powdered fuel with radiant heat primary and reheater superheaters at the sides and rear of the furnace. No economizer is used in connection with the boiler, the gases flowing to an air preheater. The Babcock & Wilcox Company furnished only the boiler of this arrangement, the superheaters and furnace equipment being supplied by other manufacturers. The boiler was designed to evaporate 240,000 pounds of water per hour as a maximum, corresponding to 8.4 pounds per hour per square foot of boiler heating surface.

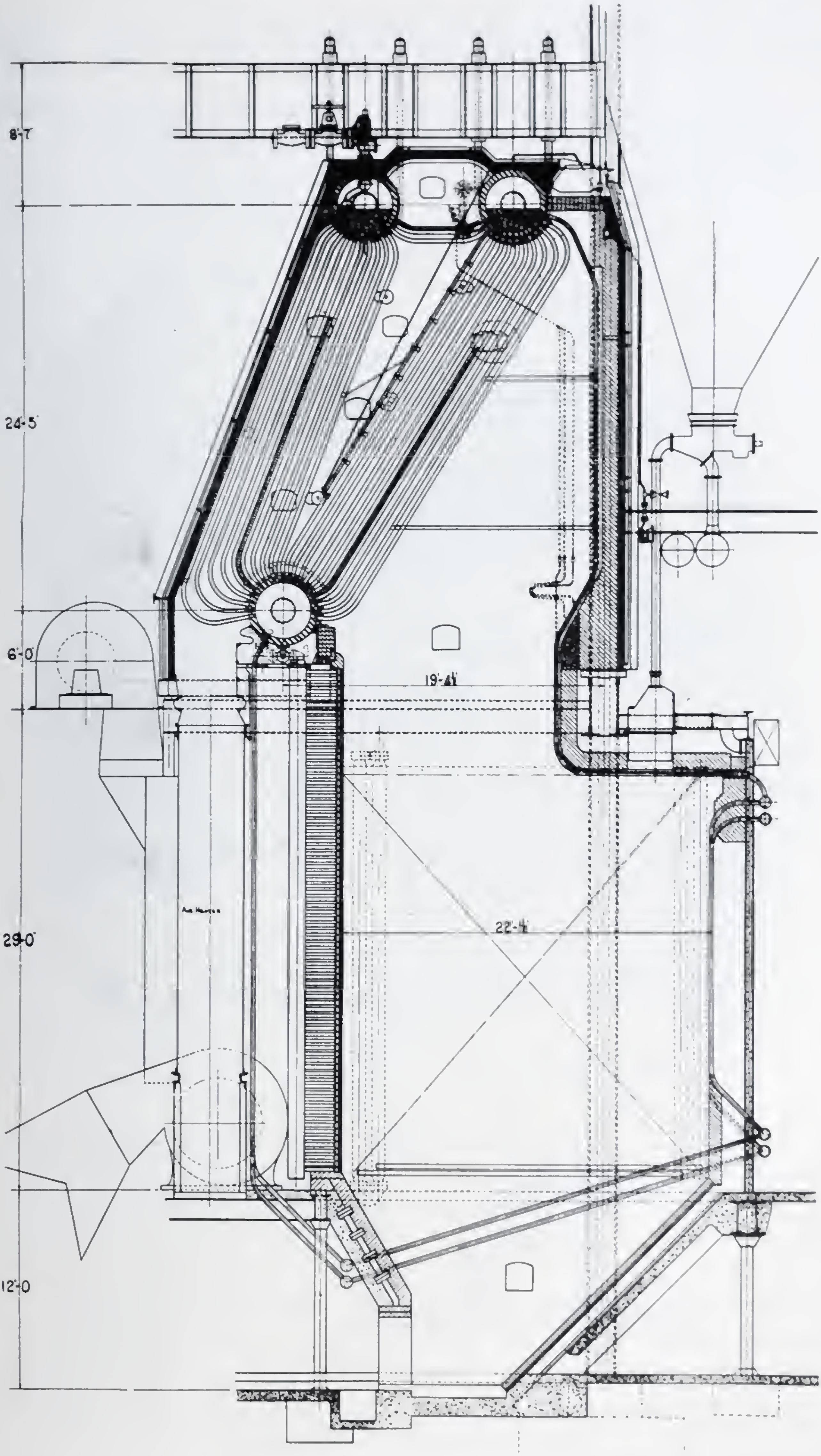

Fig. 8. Stirling Boiler Fired with Powdered Fuel.

The steam is supplied to the high-pressure turbine at 1200 pounds per square inch, and after reheating is exhausted into the mains of the power-plant and used by the regular station equipment.

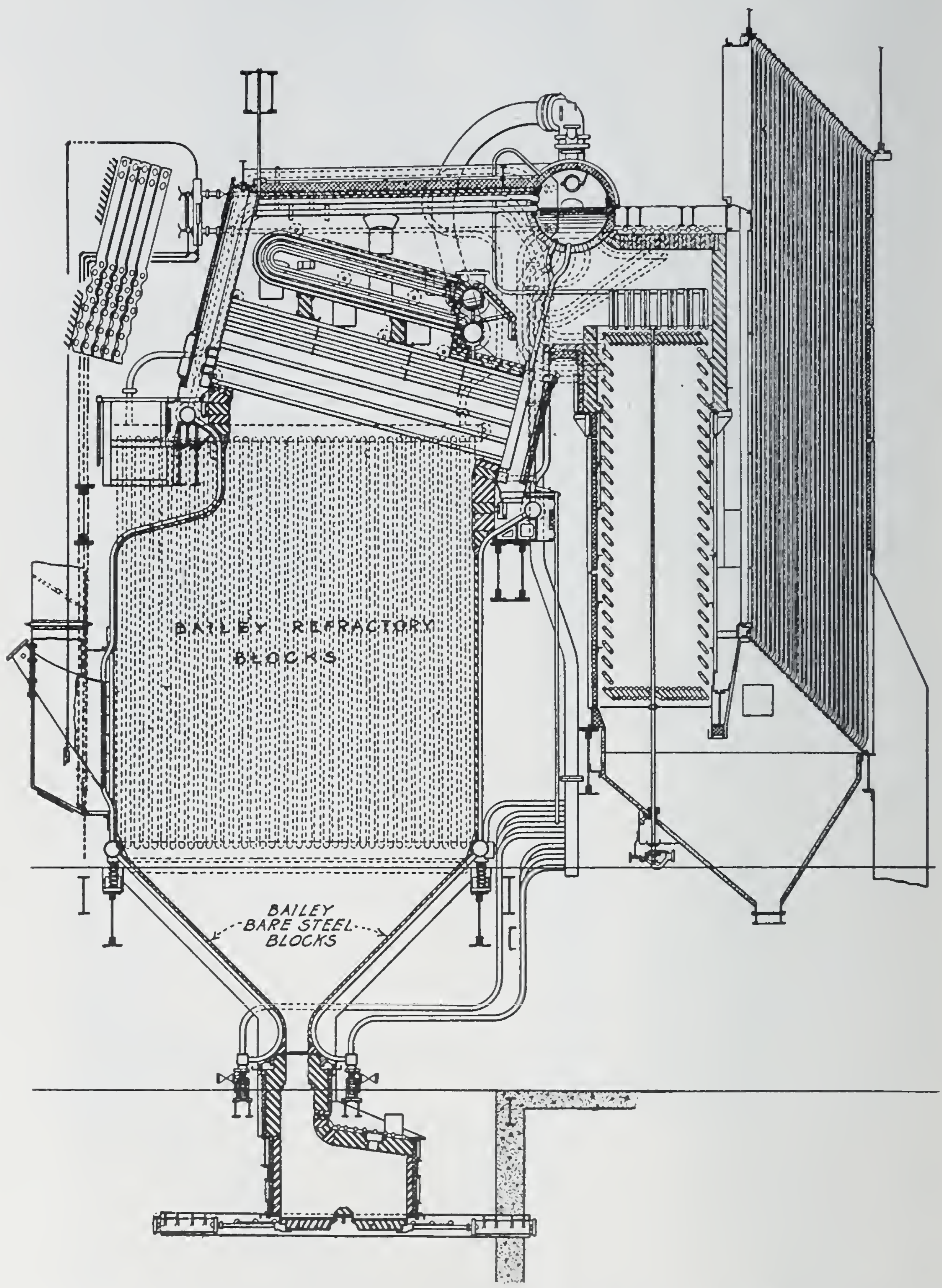

Fig. 9. Babcock & Wilcox Boiler Fired with Powdered Fuel, with Superheater, Economizer and Air Heater.

Fig. 9 is a side view of a Babcock & Wilcox boiler installed at the Calumet station of the Commonwealth Edison Company of Chicago. This boiler is built for a working pressure of 375 pounds per square inch, but it is described here in view of the fact that its development and performance in actual service led to selecting a similar design for the boilers for 800 pounds working pressure for the State Line Generating Company. The gases make a single pass over the tubes of the boiler and superheater and then pass through an economizer and air heater. The boiler proper is seven tubes high and built of 3¼-inch tubes 17 feet long. The steam and water drum is 48 inches inside diameter.

The economizer is of a loop-type counterflow design and is connected to the boiler in a special way to take care of steaming in the economizer.

The tubular air heater is of the single-pass counterflow design with inclined tube-sheets.

The boiler is fired with Fuller Lehigh Company pulverized-fuel equipment, the furnace having water-cooled Bailey refractory walls and Calumet burners. The working pressure of the boiler is 375 pounds. The heating surface of the boiler is 5938 square feet; that of the furnace wall tubes 2460 square feet; and that of the economizer 8365 square feet, making a total water surface of 16,763 square feet. The surface of the air heater is 41,700 square feet. The guaranteed output of the unit is 200,000 pounds per hour and a rate of evaporation as high as 280,000 pounds per hour has been developed, the limit being governed by the capacity of the draft fans and feed-pump. The evaporation in pounds per hour per square foot of surface is given in the following table:

	Total output in pounds		
Evaporation per square foot of heating surface based on surface of	200,000	250,000	300,000
Boiler, furnace and economizer	11.94	14.92	17.90
Boiler and furnace	23.80	29.77	35.71

Only a small portion of the economizer generates steam, and the rates of evaporation are closer to the second set of figures than the first. The temperature of the superheated steam when evaporating 250,000 pounds per hour is 700 degrees F.

Fig. 10 shows the Calumet intertube pulverized-coal burners used in connection with the Calumet boiler. The burner is attached to the

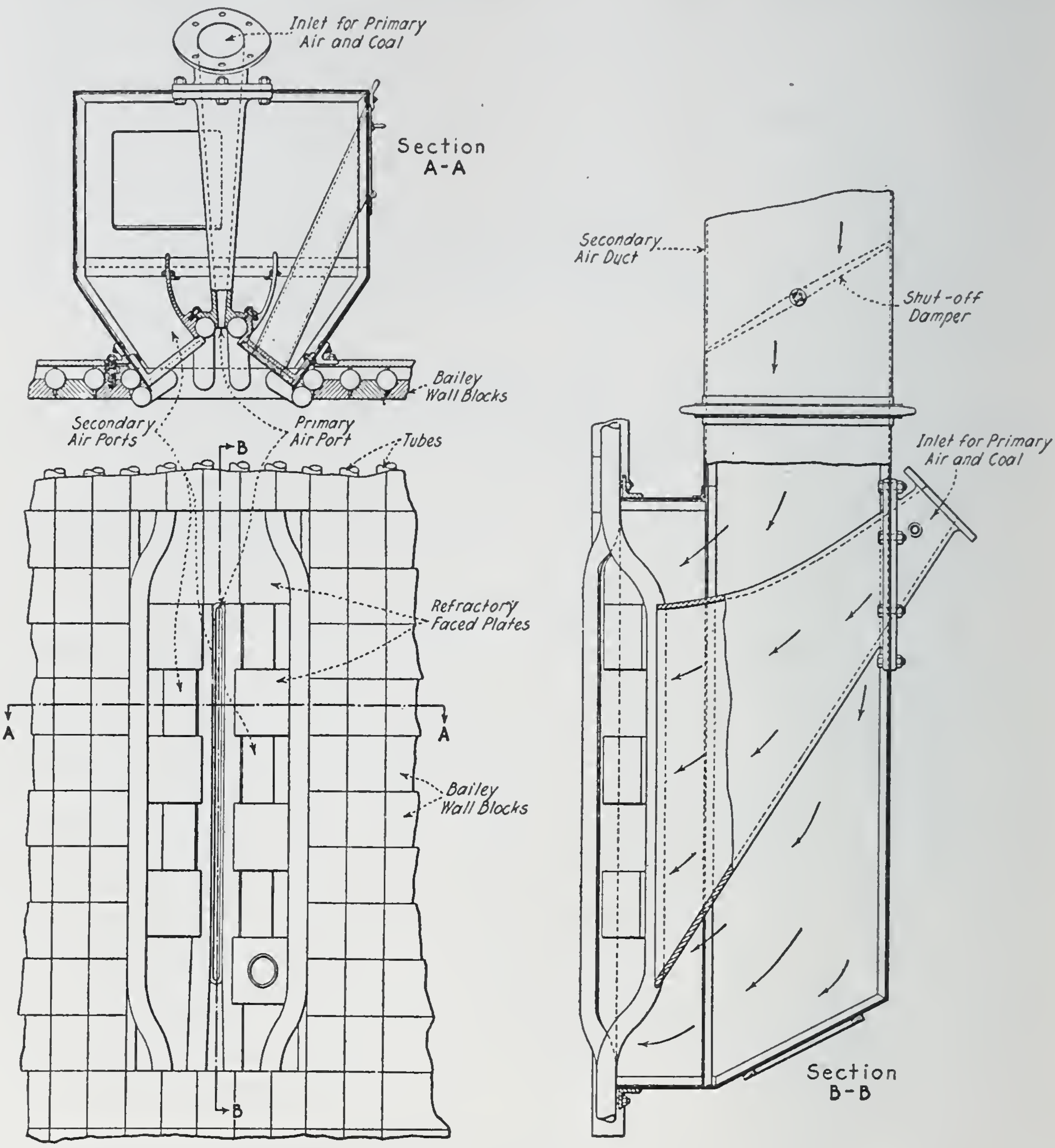

Fig. 10. Calumet Type of Pulverized-Coal Burner Used for Firing Calumet Boiler Shown in Fig. 9.

Bailey wall construction in the manner shown, and the air and powdered fuel admitted between the water-cooling tubes. The water-cooling tubes serve to prevent overheating of the ends of the burner which come nearest to the furnace. The secondary air is supplied through ports which are staggered and inclined with relation to each other at the two sides of the burner, thereby providing an intimate

mixture of air and coal close to the burner tip which results in an efficient combustion and a short flame.

Fig. 11 shows the details of the Bailey wall construction used in connection with the Calumet boiler. This wall was developed to meet the demands of high furnace capacity without entailing excessive costs for repairs. It is made up of refractory-faced cast-iron blocks,

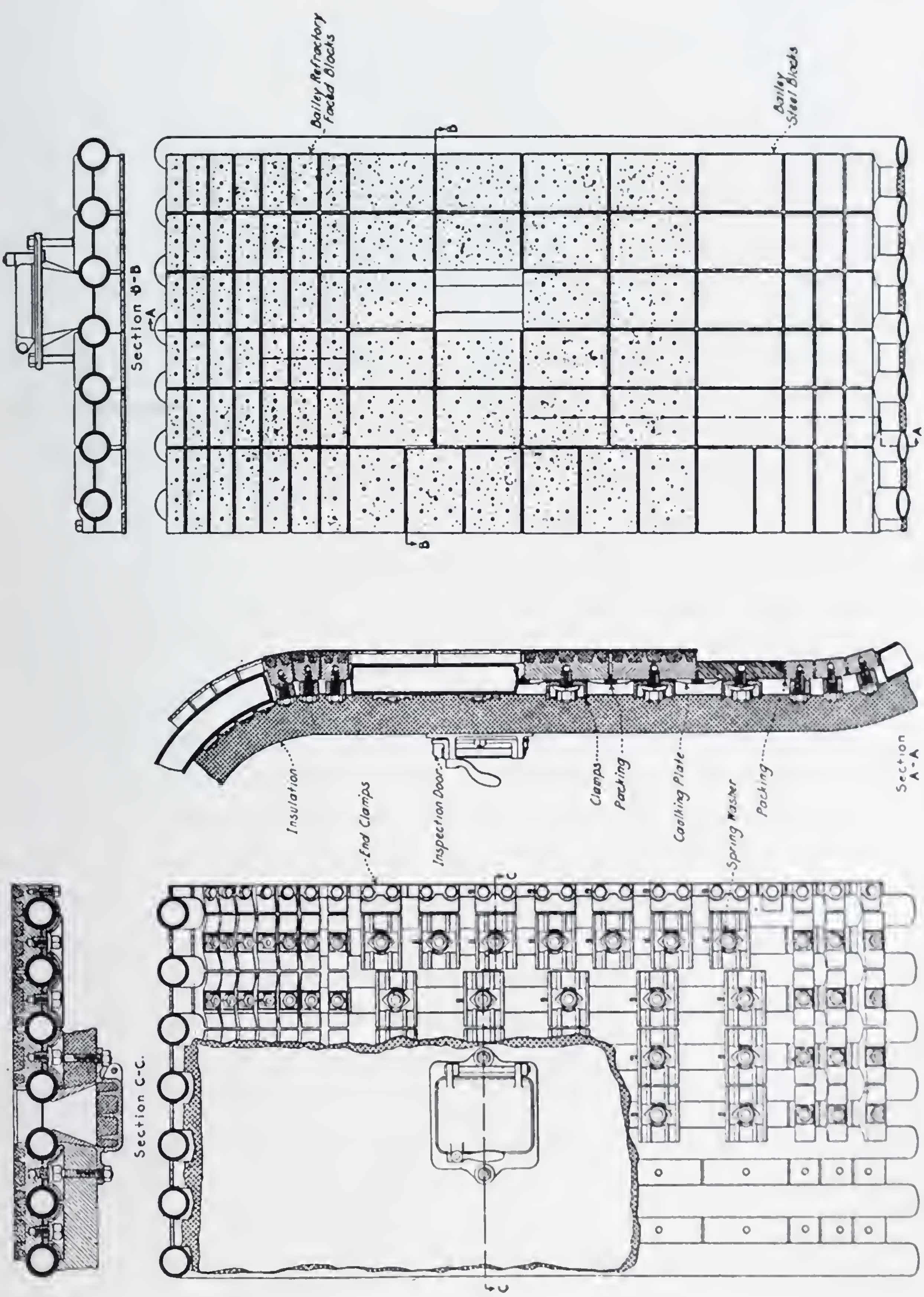

Fig. 11. Bailey Wall and Floor Construction Used in Furnace of Calumet Boiler Shown in Fig. 9.

or bare cast-iron or steel blocks clamped to 3¼-inch tubes spaced six inches from center to center and connected to the boiler circulation. The surface temperature of the refractory-faced wall may be maintained at the desired point by varying the thickness of the refractory material. The refractory-faced blocks are used for the furnace walls of the Calumet boiler, and bare steel blocks are employed for the furnace floor.

The Bailey wall construction gives an added element of safety where a furnace is water cooled. Experience has shown that bare furnace-wall cooling tubes will give more trouble than the boiler tubes through burning out in the case of poor feed-water. The use of the Bailey blocks shields the tubes from overheating and at the same time reinforces them against blowing out on the furnace side, thereby providing a safety element which is particularly desirable in the case of high pressures.

The 800-pound boilers for the State Line Generating Company are of a larger size than the Calumet boiler and are provided with forged seamless steel steam and water drums in place of the riveted drum used in the Calumet boiler. The general features of the arrangement, other than the size of the equipment, conform quite closely to that used at Calumet.

Fig. 12 shows one of the series boilers tested at the Bayonne plant of the Babcock & Wilcox Company. This boiler was described in the World Power Conference paper previously mentioned and was one of the steps in the development of the Calumet boiler. The use of higher and higher steam pressures led the Babcock & Wilcox Company to make experiments on a drumless boiler provided with a forced circulation. The first boiler of the sort was constructed over ten years ago and the name "series boiler" was applied to it. The first boiler tested had no steam and water drum. The boiler, of which a side view is shown in Fig. 10, was the second form tested and it embodied the use of a small natural circulation boiler having a steam and water drum. The natural circulation unit was made up of two-inch tubes and the steaming economizer of one-inch tubes. The surface of the steaming economizer was 3.7 times that of the heating surface of the boiler with two-inch tubes. The unit was a small one, having 187 square feet of tube surface in the natural circulation boiler, 51 square feet of superheater surface, and 685 square feet of surface in the

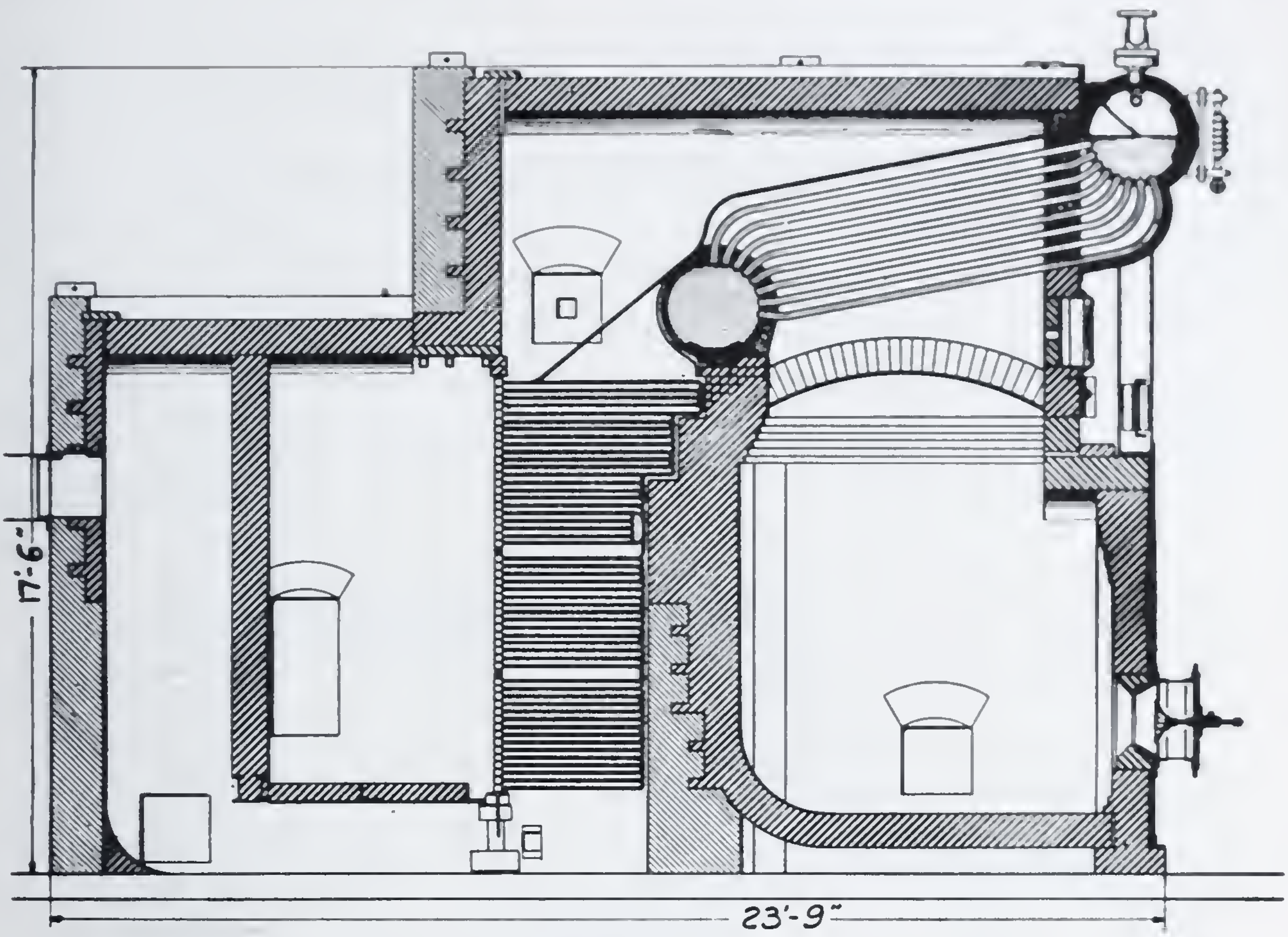

Fig. 12. Series Boiler with Natural Circulation Unit, Fired with Oil.

steaming economizer element. The boiler was fired with oil fuel and operated at 600 pounds gage pressure and was run at times to evaporate over fifteen pounds of water per hour per square foot of total boiler and economizer surface. All parts were found to operate in an entirely satisfactory way. The rate of evaporation of the natural circulation boiler with two-inch tubes was about forty-five pounds of water per hour per square foot of heating surface in the high-capacity tests. Comparing Fig. 9 and Fig. 12 it will be seen that there is a similarity between the Calumet boiler and the series boiler in that a single-pass boiler with natural circulation is placed directly above the furnace in both cases and the water is fed through a steaming economizer. The main distinction in the Calumet boiler is in the use of the Bailey furnace wall construction.

The question is often raised as to whether it may not be possible to develop a drumless boiler for high pressures. In the paper presented at the World Power Conference it was stated that we were making further tests with a drumless series boiler. It was also stated that the boiler tested was the steaming economizer part of the arrangement shown in Fig. 12. These tests were made in 1924.

The drumless boiler and its furnace which was tested are shown in Fig. 13. A portion of the arrangement in this figure, which is shown in dotted lines, is diagrammatic. The actual arrangement-ment used conformed in all of its essential features to the diagrammatic arrangement. The feed-water was fed continuously through the boiler, first passing through the tubes which acted as an economizer, and then through the tubes in which steam was formed. The steam and some excess water were then passed to a separator fitted with a gage-glass and drain. The water was drained continuously

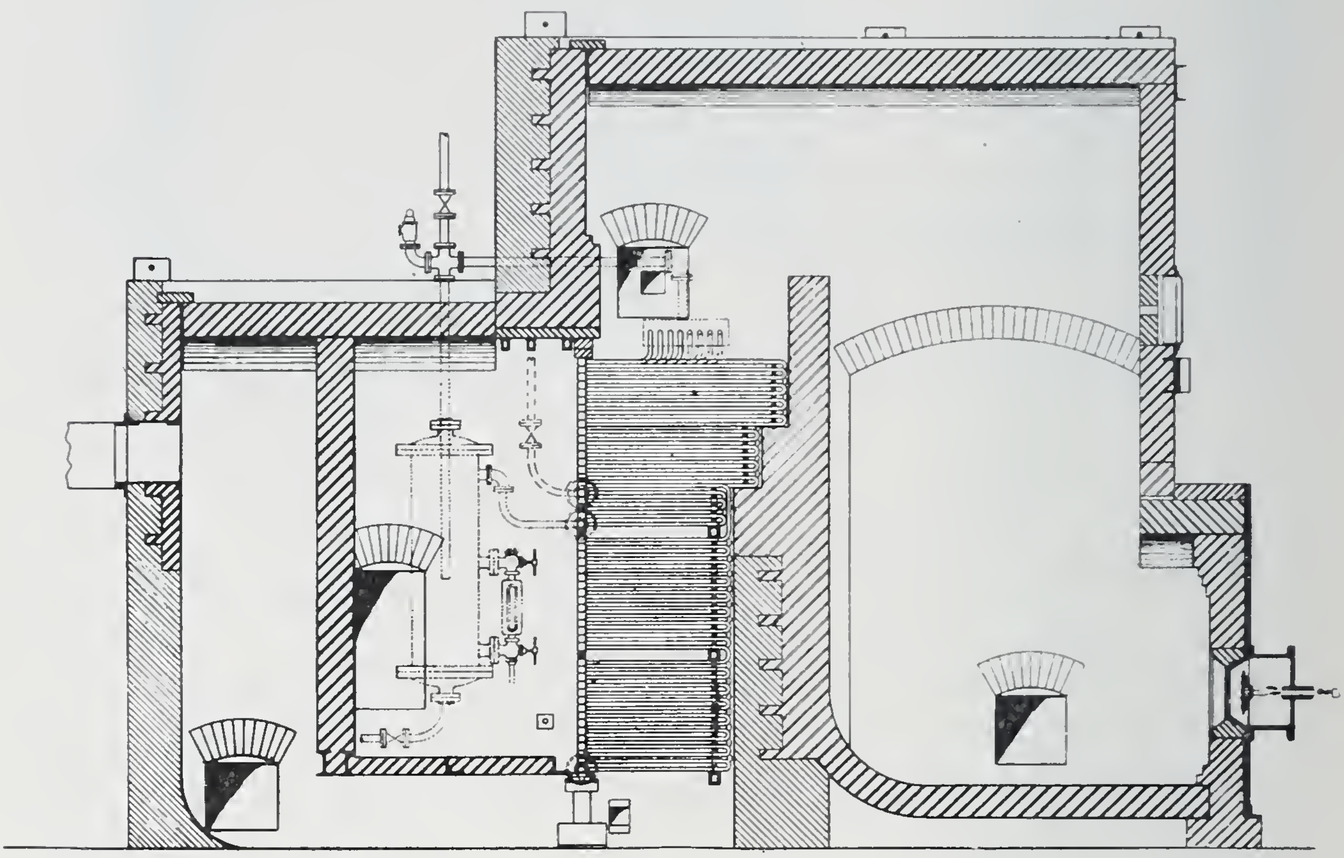

Fig. 13. Drumless Series Boiler Fired with Oil.

from the separator and the rate at which the boiler was fed was adjusted so as to hold the height of the water in the gage-glass within a given range. Steam from the separator passed to a superheater, which was so placed that there were 17 rows of the drumless-boiler tubes between it and the furnace.

There was no trouble with the operation of the boiler, which was run at from 600 to 650 pounds working pressure to a maximum of about 500 per cent. of rating based on the entire surface, including that part acting as an economizer. There was trouble with the brick-work of the oil-fired furnace; but, with a water-cooled furnace, a boiler of the sort might be successfully used for certain classes of work.

The following elements were embodied in the series boilers which were tested:

1. They were arranged to have a comparatively low frictional resistance for the flow of steam and water, this amounting to about 20 pounds per square inch with the boiler shown in Fig. 12 operated at 500 per cent. of its rated capacity on the basis of 10 square feet of total boiler and economizer heating surface per rated horse-power.

2. If arranged with tubes of the proper diameter they could be cleaned internally.

3. The water in the boilers could be drained out.

Looking into the future and considering possible developments of a drumless boiler, it is evident that by departing from one or another of the features embodied in the experimental boilers it may be possible to build a boiler of cheaper construction. No one can say what the ultimate solution will be should drumless boilers come into use for high pressures. In all such boilers the problem of starting up and stopping and of meeting sudden changes at the rate at which steam is used is a much more difficult one than in ordinary boilers. We must realize, however, that with the increasing steam pressures that are being used, and the scientific and careful management that is given to the boilers in modern power-plants, all possibilities of variation in design and construction must be carefully investigated. Additional tests are being made by the Babcock & Wilcox Company, and eventually there will be more to report respecting such boilers.

DISCUSSION

J. B. Crane:* Dr. Jacobus spoke about thickness of plate. Vertical boilers are not as well adapted for high-pressure work for the following reasons:

The bridge between holes is likely to break.

Semi-vertical boilers are more likely to give trouble with high evaporation.

Ratings with semi-vertical boilers are limited to 350 per cent.

In regard to thickness of plate, the Boiler Code of the American Society of Mechanical Engineers was enacted when it was expected that 1½ inches was as thick as it would be desirable to go on boiler-

*Ladd Water Tube Boiler Co., New York.

shells. Consequently, the rules state if the thickness of the shell is more than 10 per cent. of the radius, the outside radius must be used.

This does not make much difference when the plate thickness is 1½ or two inches, but when the plate thickness is 4½ or five inches it may mean as much as ½ inch of shell if we use the outside diameter instead of the hyperbolic mean of the inside and outside radii.

We took this up with the members of the Code Committee, and they stated that it should make no difference to us as all boiler companies were required to use the same rule. We found that it did not make much difference in the cost of the drum, as in making these drums there has to be considerable excess material in the ingot in order to retain heat for forging.

The thinner drum is more costly, as more material has to be removed from the drum, and this is a machine operation which costs more than the value of the scrap that is recovered. This means that the forged steel drums for high-pressure work actually have the factor of safety of 6 to 7 instead of the normal factor of safety of 5. This is, of course, a good thing until we find the effect of operation on these thick drums.

The effect of this higher factor of safety also tends to overcome the criticism of Dr. Jacobus that the bridge between the holes is likely to cause trouble by breaking or cracking. There is no more likelihood of this happening on the vertical boiler than on the horizontal boiler and we have never heard of trouble from this source. While the drum of the horizontal boiler is not as thick as the drum of the vertical boiler, the bridge between the holes has approximately the same strength in both of them. There is just as much chance of this happening on the horizontal boiler.

In regard to high evaporation, we have an installation with two semi-vertical boilers with 350 pounds pressure, with 3¼-inch tubes where the boiler surface is worked at 600 per cent. rating, and the two boilers have been operating under these conditions for more than a year. We have another installation with one vertical boiler, with 3¼-inch tubes, with 375 pounds pressure operating for over a year at 600 per cent. rating. So far, no difficulty has been experienced with these tubes in any of these boilers.

Dr. Jacobus states that it takes 20 per cent. more surface with the semi-vertical boiler than with the horizontal boiler to give the

same exit-gas temperature. We believe this to be largely a matter of design, and even with the 20 per cent. more surface the vertical boiler will be cheaper and more efficient on account of less radiation loss.

The vertical boiler has one distinct advantage over the horizontal boiler in pulverized-coal firing in that we obtain a longer flame travel and consequently more complete combustion before the gases enter the boiler tubes. We believe this was one reason that influenced Mr. John Anderson in choosing the vertical boiler for high pressure for Milwaukee. Prior to the purchase of the high-pressure boiler Mr. Anderson has used nothing but horizontal boilers, so that he can not be considered as biased in favor of the semi-vertical type.

On high-pressure work, with condensing plants, the steam is generated in the boiler at 1400 pounds pressure, passed through the primary superheater, thence to the high-pressure turbine, and back to the reheater or secondary superheater located in the boiler setting. The nearer we can place the superheater and reheater to the furnace the better regulation we can secure on them, and the less surface is required for securing the necessary temperature. This can be done much better with the vertical boiler than with the horizontal boiler.

We believe that the high-pressure boiler is here to stay. It takes 120 B.t.u. to raise steam from 400 to 1200 pounds pressure, which means that it will take from 4000 to 7000 B.t.u. per kilowatt-hour at the switchboard for the electricity that is made with the turbine unit at 1400 pounds pressure. If this is superimposed on a 20,000 B.t.u. plant, and all of the steam passes through the high-pressure turbine, it will reduce the 20,000 B.t.u. plant to a 16,000 B.t.u. plant, which means that a lot of boiler houses at 250 pounds pressure, which has been considered out of date, will be given a new lease of life by the installation of high-pressure units. On industrial plants using exhaust steam for process work still greater savings can be made.

J. C. Hobbs:* It seems to me that high-pressure boiler development can be reduced in the last analysis to about two elements—cost and reliability. Speaking of costs often reminds me of a discussion which took place in a group which contained at least one having thoughts about things other than boilers. They were trying to determine who was the greatest inventor. James Watt was nominated.

*Superintendent of Power, Diamond Alkali Co., Painesville, Ohio.

Another mentioned Edison. Henry Ford was included in the list. But the discussion was closed when one without technical training spoke up and said, "I don't know what his name is, but the fellow who invented interest was no slouch."

In discussing high-pressure steam apparatus the matter of cost is of primary importance. Fortunately, however, the cost of high-pressure parts is a comparatively small percentage of the total cost of the power-station. The use of high-pressure equipment does not increase the cost of the real estate, the building, nor much of the equipment. Due to the greater economy a smaller steam consumption is obtained, and the cost of some equipment, like condensers, is actually decreased.

The total costs of the completed project, rather than a comparison of the boiler cost, should be used to determine the proper pressure.

Only two items of operating cost are greatly affected. One is the steam consumption of the main power-generating units, and the other is the cost of pumping the boiler feed-water against the higher pressure. It is believed that the use of more efficient boiler feed pumping equipment will result in greatly reducing the amount of power required.

Contrary to what some might expect, the high-pressure units show greater reliability than most low-pressure units. This was noticed particularly during my inspection of most of the high-pressure installations in this country. In Milwaukee they told me that they had fewer leaks and less trouble in starting up the 1250-pound, high-pressure plant than they ever had with a unit of their 350-pound equipment. It is believed that the high-pressure steam equipment will become just as popular and profitable in the future as high-voltage electrical equipment has proved to be.

There has been a very large amount of 600-pound equipment built and put into successful service. Two 1200-pound installations are operating. Is it likely that an intermediate pressure of 800 or 900 pounds will be developed? Can we expect the greatest amount of thought and development work to be concentrated on the 600-pound apparatus for the nert few years, or will higher pressures be preferred? What is the status of the development of boilers to be operated at the critical pressures, or around 3000 pounds per square inch?

D. S. JACOBUS: The statement in the paper that the boilers for the State Line Generating Company will be built for 800 pounds pressure is a reply to the question as to whether intermediate pressures will be used between the 650 and the installations of 1200 to 1400 pounds which are now operating. The most economical pressure at which to operate a plant is one that can be determined only by a careful analysis involving all of the factors which apply to a particular case. Mr. Hobbs mentions the development of boilers to be operated at the critical pressure, or around 3000 pounds per square inch, and points out the importance of considering the work required for pumping the feed-water at high pressures. This is certainly an important feature and one that should be included in any analysis bearing on the highest pressure that can be economically used.

Jacob Perkins was a pioneer in the construction of high-pressure boilers. In a book entitled "History and Progress of the Steam Boiler," by Elijah Galloway, published in London in 1830, the statement is made that water was forced through a part of the Perkins steam generator which was kept full of water under the pressure of a heavily loaded valve, and at each stroke of the engine a certain quantity of water heated to about 700 or 800 degrees F. was discharged into a part of the generator containing no water but kept at a temperature of about 1000 degrees F. Heating the water to a temperature of from 700 to 800 degrees F. would involve operating at or near the critical pressure of, say, 3000 pounds per square inch. Cast-iron bars five inches square, having longitudinal holes through them 1½ inches in diameter, were used in the boiler in place of tubes.

THOMAS G. ESTEP:* In preparing material on high-temperature, high-pressure cycles in connection with my course in steam power-plants I have always been at a loss what properties of steam to use in the calculations. Professor Goodenough, in his tables, shows that the total heat content decreases with an increase in pressure above about 475 pounds, while Callender gives a continuously increasing heat content with an increase in pressure.

Some European investigators, particularly in Germany, have shown that there is a certain amount of dissociation of steam at high temperatures. If an average steam temperature of 800 degrees F. is

*Associate Professor, Mechanical Engineering, Carnegie Institute of Technology, Pittsburgh.

obtained, it is evident that a much higher temperature must prevail in certain sections of the superheaters. Has there been any evidence of dissociation where high-temperature steam has been used?

D. S. JACOBUS: Callender's experiments do not give the same results as those that are being obtained in the work in progress in this country to establish a new steam table for high pressures. This work is being done at the Massachusetts Institute of Technology, at Harvard University, and at the United States Bureau of Standards, and preliminary results of these experiments have been very carefully worked up by the General Electric Company. Perhaps Mr. Warren can tell us something in regard to the magnitude of the differences.

The question has been raised regarding non-condensable gases in superheated steam. There would seem to be no reason why non-condensable gases should be present, unless the temperature of the superheater tubes is high enough to form black oxid of iron in the tubes, which naturally would result in the burning of the tubes.

J. A. POWELL:* We have been investigating steam pressures of 400 pounds, and above, as applied to electric generating plants, and we find that the turbine, boiler, economizer, superheater, reheater and general arrangement, as well as the price of fuel, and the load-factor, have a great bearing on the most economical steam pressure.

There are a lot of things that favor higher pressures except the thermal gain; for example, with higher pressures more steam may be bled for feed heating, resulting in a reduction in the size of economizer and boiler, part of the gas passing through an air heater which is not affected in cost by the steam pressure. The condenser is reduced as the amount of bled steam is increased. It is interesting to note that in a 1200-pound plant only 70 per cent. of the steam generated gets to the condenser.

With increased pressure and reheat, additional capacity is gained over the same size boiler plant without reheat, and with plants arranged like the Edgar station this additional capacity is gained with practically no building cost.

It is quite a problem at this time to decide what type of boiler is best suited for higher pressures—whether the bent type or straight

*Mechanical Engineer, W. S. Barstow & Co., Reading, Pa.

tube—and whether the superheater and reheater should be convection or radiant, or a combination of either convection and radiant, or steam and convection.

In our first studies we thought that with the 1200-pound plant it would have to be superimposed upon a lower pressure plant, and that the high-pressure load should be considered as a base load. The more we studied the load on the various stations of our system the more we were convinced that the high-pressure plant should be able to handle its load just the same as all other plants. With all steam governed by the high-pressure unit, and allowing the pressure between high- and low-pressure turbines to vary with load, it was found that a greater reheat could be added at light loads than at heavy loads and, consequently, it would result in very good performance.

Due to the gained capacity being proportional to the pressure, and as both 600- and 1200-pound construction are very similar, it is expected that the capital cost will be 14 per cent. and six per cent., respectively, over a 400-pound plant. Our studies were based on units of 35,000 to 50,000 kilowatts, coal at $5, and 55 per cent. load-factor, and our conclusions justify the 1200-pound plant over either 400 or 600 pounds. With units larger than 50,000 kilowatts, the 600-pound may appear more favorable than in our studies. For lower load-factors and cheaper coal than we have considered, the 400-pound plant will make a more favorable comparison.

H. B. Mann:* May I ask Dr. Jacobus a question? In industrial plants if we attempt to install a 1200-pound turbine with present equipment, taking advantage of the general scheme used at the Edgar station, it would make it a rather small system. Also, in water-works pumping, where turbines have been developed to a very high state of efficiency, our turbines on large-size units use approximately 20,000 pounds of steam per hour. I want to ask whether they have designed or furnished high-pressure boilers in approximately those sizes—say 20,000 to 30,000 pounds of steam per hour, or is there any fundamental objection to the development of those sizes?

D. S. Jacobus: We have built for process work a boiler for 1200 pounds working pressure, having 3820 square feet of heating

*Vice-President, Dravo-Doyle Co., Pittsburgh.

surface, which would come within the range of capacity specified by Mr. Mann. There is no objection to the development of high-pressure boilers in such sizes other than that the cost of the boilers as compared to larger boilers for power-generating stations will, of course, be greater per unit of capacity.

H. B. Mann: Well, would you state any approximate ratio of cost of boilers?

D. S. Jacobus: I can not give you the ratio of costs. In any event, the only way to determine whether a boiler of the sort would be applicable would be to consider each case by itself and determine whether the investment would be warranted. In the case of the boiler I spoke of, it was necessary to have high-pressure steam for the operation of the process and this warranted going to the expense of the high-pressure boiler.

HIGH-PRESSURE STEAM-TURBINES†

By G. B. Warren*

The present successful commercial application and use of very high steam pressures in large steam-turbine prime movers marks another important advance in the production of power from fuel.

By high pressures, I mean pressures of from 550 to 1200 pounds, or more, per square inch. The use of such high-pressure steam is permitting reduced heat consumption of the main units, and the building of turbines of increased capacity with given limitations in the low-pressure end is also greatly facilitated.

The General Electric Company is in a position to furnish reliable turbines for any steam condition and capacity which may be desired by the operating companies and station builders. Whether or not high-pressure turbine installations similar to these described here would be justified in other cases we are not in a position to determine. This point can be decided only by those engineers who have made a particular study of power-plant design, and then only after thoroughly taking into consideration local conditions of load-factor, demand, capacity of units, price of coal and equipment, existing equipment, and many other things.

The turbines which we have built so far for these conditions, although new developments, have been completely successful, and we feel confident in saying that the use of high-pressure steam can be approached with complete confidence that the turbines will be easy to operate, reliable, and successful in every respect.

The purpose of this paper is to show the possibilities which lie in the use of higher steam pressures from the turbine standpoint; to indicate the changes in turbine design brought about by these higher pressures; and to describe and illustrate some of the machines which the General Electric Company has built for the utilization of higher steam pressures. Out of this, and the papers presented by Mr. Jacobus and Mr. Morehead together with the discussion which follows, should come a better understanding of the subject by interested engineers, which understanding should aid in establishing that confidence which is necessary before any great investment can be brought about in this type of power-plant.

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†Presented at conference on High Steam Pressures, October 17, 1927. Received for publication January 6, 1928.

The possibilities for thermal improvement which lie in the use of higher steam pressures, temperatures and the more advanced steam cycles are appreciable; for instance, in connection with the condensing cycle, an improvement of 7½ per cent. results from raising the pressure from 200 to 400 pounds gage with constant initial temperature, while a further increase to 600 pounds gage gives an additional three per cent. reduction. If raised to 1200 pounds, a six per cent. further reduction in fuel consumption is obtained.

If a turbine is being run non-condensing or with back pressure in some industrial plant in which the exhaust steam is used for process work, the possibilities of obtaining increased power from the process steam are even greater. In this connection the power is obtained at a net expenditure of heat chargeable to power production of some 4000 B.t.u. per kilowatt-hour, when taking into account all turbine and boiler losses. Thus, if a given amount of heat is required for process work at atmospheric pressure, the power which can be obtained from a turbine exhausting to the process headers is increased 16 per cent. in going from 200 to 400 pounds gage, and again 14 per cent. in going to 1200 pounds gage initial pressure; whereas, if steam is required at 100 pounds gage pressure, the power which can be obtained from any given quantity of steam is increased 68 per cent. in changing from 200 to 400 pounds and again 40 per cent. in changing to 1200 pounds.

In condensing operation, the gain to be obtained in going to higher pressures is appreciably increased by the resuperheating of the steam at some point in its cycle. Although, in general, this is somewhat better so far as the theoretical cycle is concerned, its main advantage is on account of the decided reduction in the moisture content of the steam which is thus obtained in the lower stages of the turbine. This reduction in the moisture content in these stages materially raises the turbine efficiency. Since the formation of moisture is greatly increased in condensing turbines by increased initial pressure, it follows that resuperheating is more desirable in connection with such higher pressures.

In general, resuperheating is carried out in one of two ways:

1. By piping the steam, after a part of its expansion, back to the boiler room and resuperheating it, after which it is returned to the turbine at or near the initial steam temperature.

2. By resuperheating the steam, after a part of its expansion, by means of the condensation of high-pressure steam from the boiler. This is generally done near the turbine in a closed heater and the resuperheat temperature so obtained is generally 15 to 20 degrees F. below the saturation temperature of the initial steam. A net reduction in heat consumption is, of course, obtained, even after charging up the heater steam to the turbine.

One of the most important improvements which has been made in the power-plant field in recent years has been the wide adoption of regenerative feed-water heating by means of the extraction of steam from the main units into a series of heaters through which the feed-water is returned in its passage from the condenser to the boiler. Work is thus obtained from steam which is not condensed in the condenser. The work so obtained is produced at an efficiency approaching 100 per cent., and so the total cycle efficiency is increased thereby.

The use of increased pressures, temperatures, resuperheating, and extraction cycles has increased the power which can be obtained from a given quantity of steam passing to the condenser, and so has permitted a considerable increase in turbine capacity with any given last-stage dimension.

Contrary to the conception current a few years ago, the gain obtained by higher steam pressures is not reduced by diminished turbine efficiencies. This difficulty has largely been overcome by the use of cross or tandem compounding of the machines. Such separation of the high-pressure from the low-pressure elements has permitted speeds, bucket lengths, and diameters of shaft, wheels, and packing which have made the efficiency of this end of the high-pressure turbine the equal or even the superior of the equivalent part of the single-cylinder, moderate-pressure turbine.

Increased size of units has brought with it the necessity of providing multiple points of admission which will permit of high economy over a wide range of load.

A careful study of the economy of power-plant design will show that not only does the turbine efficiency at its average load determine the fuel consumption, but its efficiency at maximum load will have a decided influence upon the installed capacity which can be obtained from a given investment in the rest of the station. It may even happen, therefore, that a larger and so more efficient turbine at full load

will result in a lower cost of the plant as a whole per kilowatt of installed capacity, even though the turbine itself may cost more per kilowatt of capacity.

So far, the use of higher pressures and temperatures has not radically changed the materials used in turbine design. Running stresses and susceptibility to corrosion have largely governed the selection of these materials rather than stresses due to pressure or temperature. However, if temperatures greater than 750 degrees F. are used, changes in materials may have to be made. It has already been necessary to strengthen shells, improve materials for shell bolts, and give much more study than formerly to the design of flanges and joints. Furthermore, the most painstaking attention has been paid to those details of turbine design which would permit the turbine to adjust itself to the changing temperatures and pressures resulting from starting, shutting down, and the violent changes in load which result during operation.

Fig. 1-7 show the development of the General Electric turbines designed for initial pressures above 550 pounds per square inch.

Fig. 1 shows the 35,000 to 50,000 kilowatt-units, of which six have been built and are in successful operation on steam pressure of 600 pounds gage at the Philo, South Bend, and Stanton plants of the American Gas & Electric Company. These were the first large, high-

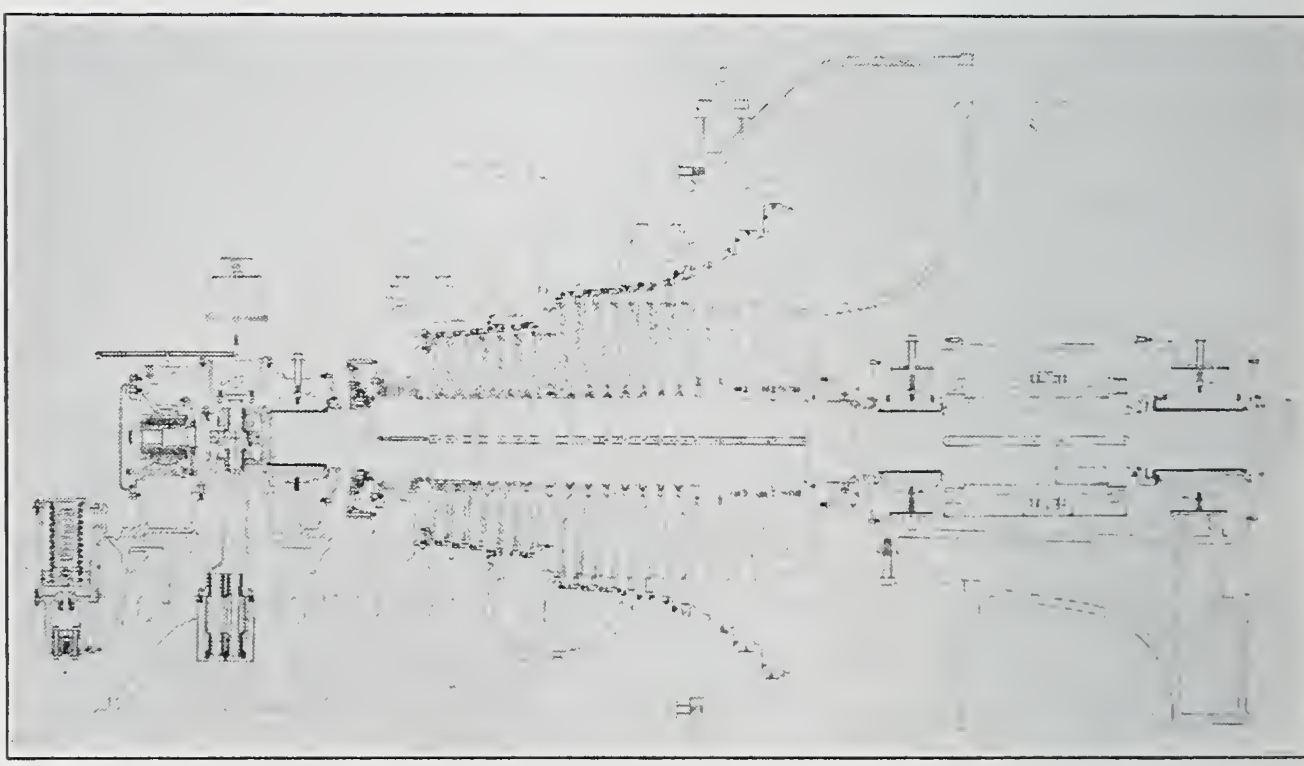

Fig. 1. Curtis Steam-Turbine of 35,000-Kilowatt Capacity.

pressure, resuperheating machines in successful commercial operation. They are of the one-cylinder, one-valve, base-load type.

Fig. 2 shows the tandem-compound, 40,000-kilowatt, resuperheating, one-valve, base-load turbines designed and built for the

Fig. 2. Tandem-Compound Steam-Turbine.

Columbia station of the Columbia Power Company. These have been in commercial operation for about two years.

Fig. 3 and 4 show the high-pressure and low-pressure units, respectively, of the 90,000-kilowatt Crawford Avenue turbines. These are four-valve, cross-compound turbines with resuperheating by live steam to about 450 degrees F. between the two elements of the turbine.

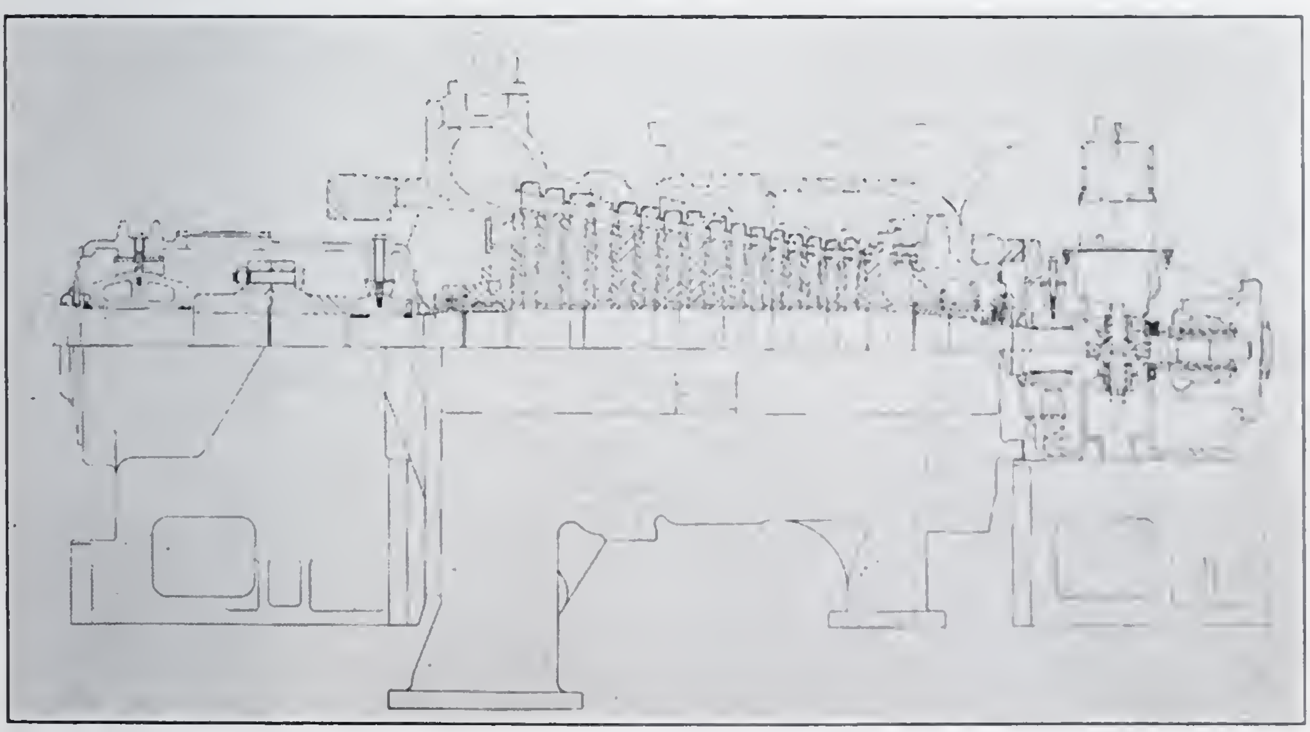

Fig. 3. High-Pressure Unit of 90,000-Kilowatt Steam-Turbine.

Fig. 5 shows one of the first turbines the General Electric Company designed and built for 1200 pounds gage initial pressure with 300 to 375 pounds gage back-pressure. A number of these turbines are now in commercial operation, discharging steam into the main steam headers of the stations in which they are installed so that the steam may be further utilized in the existing lower pressure turbines.

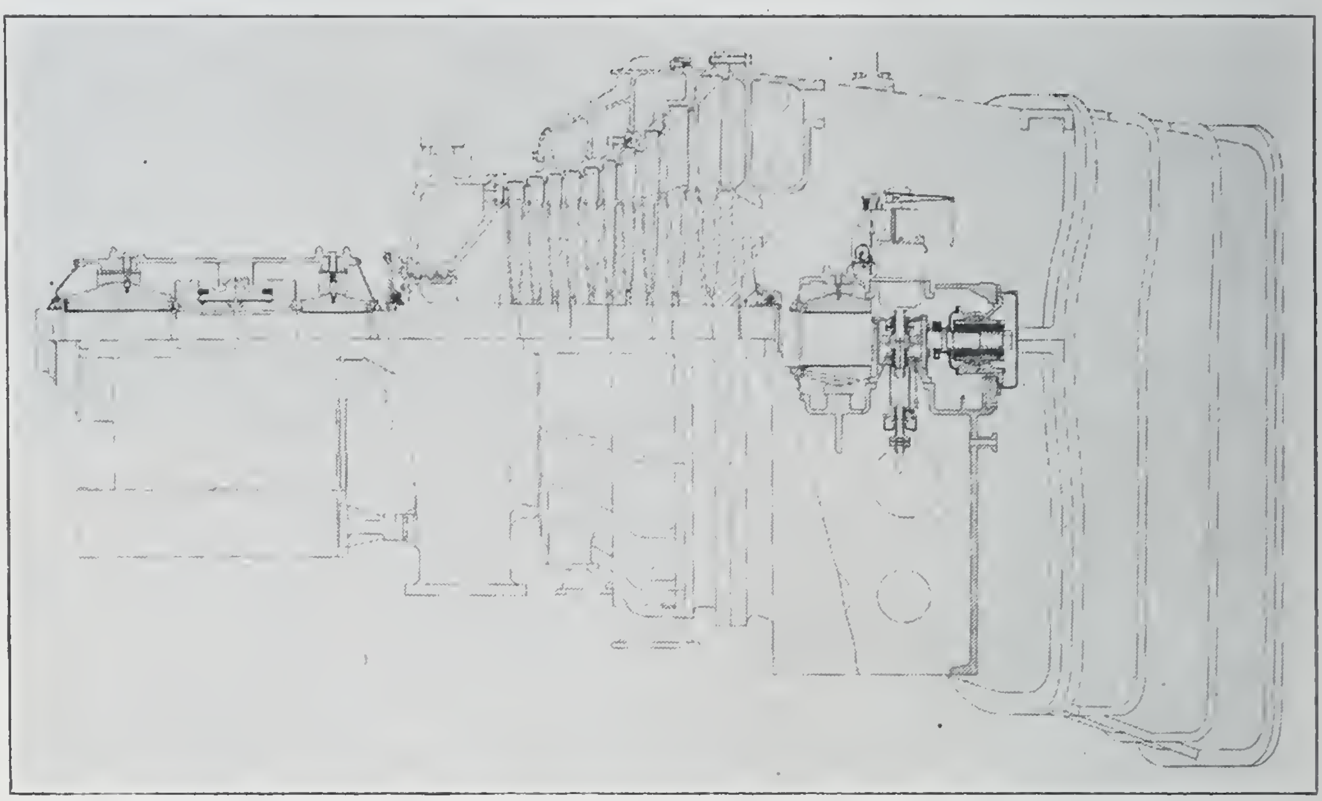

Fig. 4. Low-Pressure Unit of 90,000-Kilowatt Steam-Turbine.

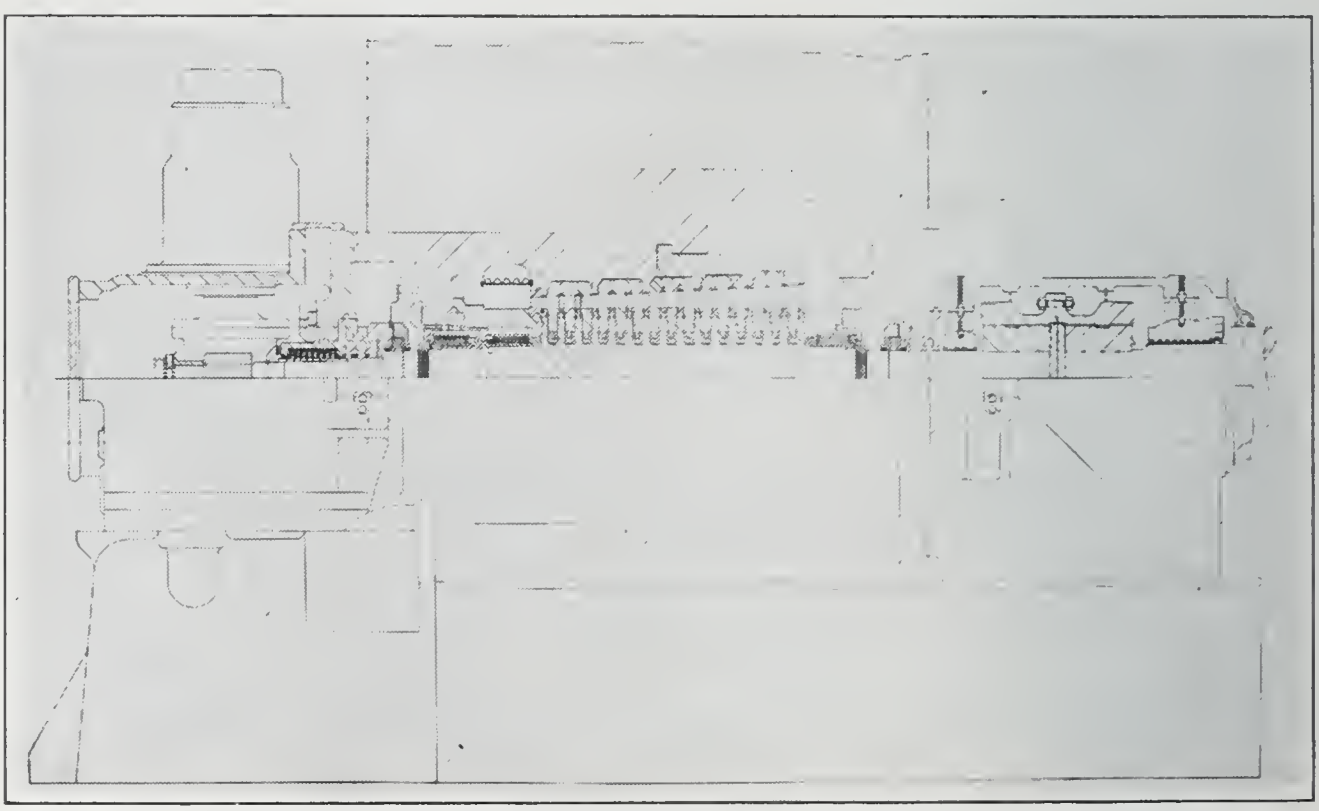

Fig. 5. Section of 10,000-Kilowatt Steam-Turbine.

Fig. 6 and 7 show the high-pressure and one of the low-pressure elements of the triple-compound, 208,000-kilowatt turbine designed for 600 pounds gage initial pressure for the State Line station. This high-pressure turbine has four points of non-throttling admission and so gives a very flat heat-consumption curve over a wide range of load. The two low-pressure elements are identical, and the steam is

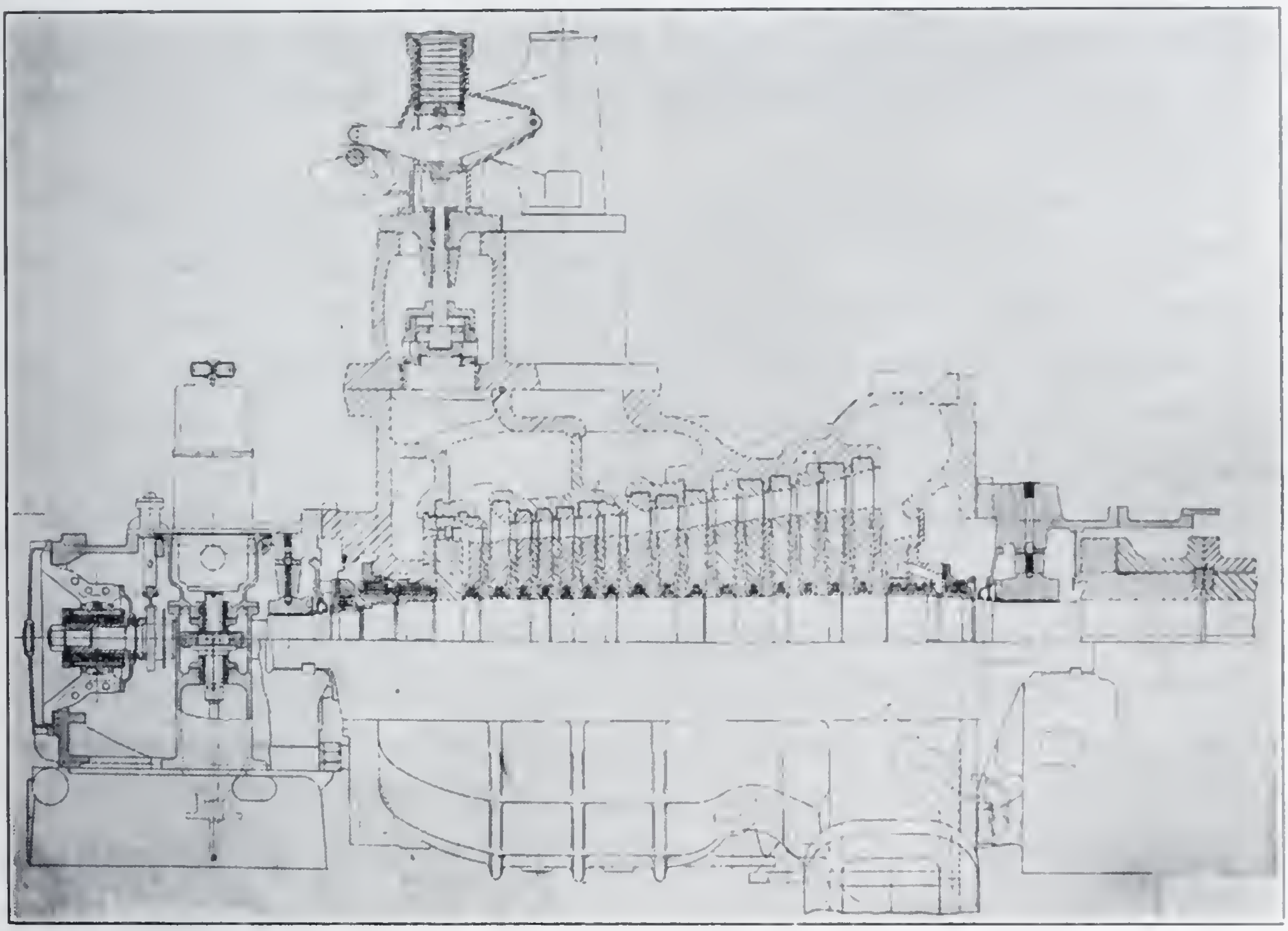

Fig. 6. Section of 76,000-Kilowatt Steam-Turbine.

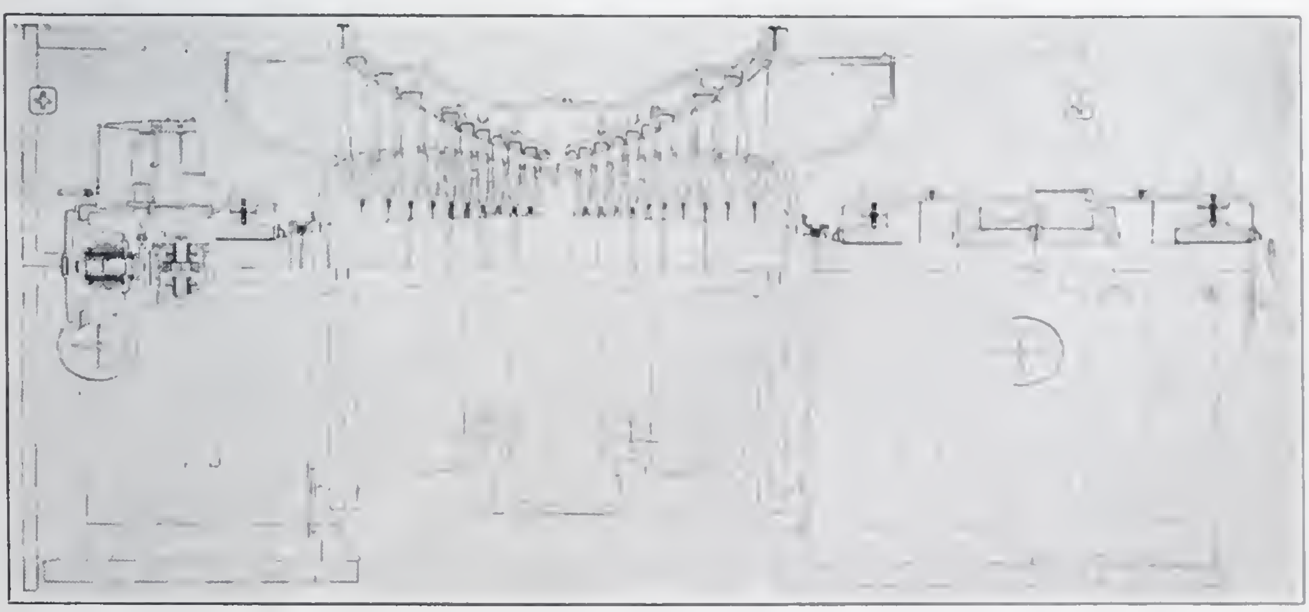

Fig. 7. Section of 66,000-Kilowatt, Double-Flow Steam-Turbine.

resuperheated by live steam to 500 degrees F. before passing into the low-pressure turbine. On this machine five stages of feed-water heating are to be used for the first time in commercial service.

DISCUSSION

Philip G. Darling:* There has been quite a lot said here to-day about high-pressure boilers and high-pressure turbines, but nothing has been mentioned of any method of control device in connection with safety-valve blow down, which is considerable on high-pressure service.

As steam pressures increase, the losses and inconvenience of safety-valve blowing increase. The standard four per cent. blow down of spring-loaded, power-plant safety-valves amounts to 50 pounds or more on the valves at 1200-pound plants and to half of this on the 600-pound plants. To reduce the losses involved in this blow down, the Ashcroft Manufacturing Company has developed an electrically operated relief valve which reduces the blow down to less than one per cent.

The valve consists of two separately located parts—one the valve itself and the other the pressure electric control box or panel, the former being located generally on the superheater outlet and the latter in the boiler room at the operating floor.

The valve is piston operated from the steam pressure itself by means of a pilot-valve which bleeds a small amount of steam from a chamber above the piston. The pilot-valve is operated by the pull of a solenoid at the end of a multiplying lever. The control box contains a specially developed double Bourdon spring pressure-gage supplemented by a long helical spring to give great sensitiveness. This gage actuates the points for making and breaking electric current to the solenoid.

By setting this valve for a pressure just below that of the safety-valves on the boiler, it handles all of the normal operating steam relief with a blow down of one per cent. or less, reserving the safety-valves in continued perfect condition (since never blown normally) for emergencies.

The disk of this valve is never in a nearly balanced condition as is the case with spring-loaded safety-valves when near their popping

*Ashcroft Manufacturing Co., Bridgeport, Conn.

point, but always has a heavy steam load holding it tight to its seat. It permits discharging against a high back-pressure and its action is in no way impaired by starvation or restriction at the inlet. It is thus practically proof against unfavorable conditions both of installation and operation.

The recommended installation places the valve on the superheater outlet, where its operation protects the superheater and connects its control gage to the drum, which eliminates the variable pressure drop through the superheater as a factor in its operation.

W. H. Armacost:* The use of high-pressure boilers and turbines has opened up a new field in superheating steam (a more appropriate name would be reheating). Up to the present time, reheating has been accomplished by using a secondary convection superheater placed in the boiler setting in the path of the flue-gases, after the primary superheater, except in one instance—the Lakeside high-pressure boiler installation—where the reheater is of the direct radiant type placed in the back wall of the furnace.

Another type of reheater which is being used is the "live-steam reheater" which is being installed at Crawford Avenue station and is placed between the high-pressure and low-pressure cylinders of the compound turbine. A 10-foot length of 38-inch pipe being left out between the turbine and the reheater is accommodated in this space, eliminating any additional piping and thereby avoiding undue pressure drop, which is of considerable importance at the reheating pressure of 50 pounds per square inch.

The reheater will add approximately 200 degrees of superheat to a half million pounds of steam when running at normal load and will use steam at 550 pounds pressure, and 725 degrees for the heating medium. The regulation of the reheater will be by a throttle-valve on the high-pressure-steam feed line.

One objection to the live-steam reheater has been the limit to which steam can be superheated; but, when it is found advisable to reheat to a higher degree of temperature than could be attained with a live-steam reheater, due to the limited temperature of available high-pressure steam, a gas reheater could be used with a live-steam reheater in series, using the live-steam reheater as a means of regula-

*Mechanical Engineer, Superheater Co., New York.

tion, although placed first in the series, and finishing off the temperature with a gas reheater. This arrangement gives complete control for a uniform temperature over the complete load range on the boiler, as it is practically impossible to control the final temperatures from a primary superheater and a reheater in the same setting without some means of regulation.

The outlook is favorable for this type of reheater, due to its simplicity and ease of operation; also its adaptability to high pressures.

J. C. HOBBS:* The papers and discussions so far seem to cover new plants only. No emphasis has been placed on the addition of high-pressure units to existing plants. The largest loss in the present power-stations is to the condenser, amounting often to 75 per cent. of the fuel burned. The superimposing of a high-pressure unit, exhausting into the present steam mains of an existing plant, eliminates the condenser loss for the additional equipment. This was accomplished in Boston and Milwaukee, where the original pressures were 350 pounds. If they found it economical to use high-pressure equipment with a back-pressure of 350 pounds, then there are hundreds of installations throughout the country where greater relative economy can be obtained, because the present steam pressures in most common use range from 275 pounds down, with an average probably below 200 pounds. An analysis of the cost of additional power which can be generated by superimposing the high-pressure unit on the existing plant will show that the fuel cost will amount to only about one-fourth of the present fuel cost per unit of power. The saving of 75 per cent. of the fuel costs should be much greater than the additional fixed charges per unit of boiler capacity. In fact, the installation of new boilers will in many cases result in an increased boiler efficiency which, taken with the decreased labor cost, is great enough to offset the fixed charges on the new boiler equipment.

Mr. Warren made the statement that in connection with the ratings of turbines it is not desirable to use a turbine which has a very high overload rating. He intimated that we would have to build a boiler house 12 per cent. larger in order to make enough steam to run this turbine at 12 per cent. less economy. I wonder if he has taken into account the fact that we can not afford to run the boiler

*Superintendent of Power, Diamond Alkali Co., Painesville, Ohio.

house at maximum rating for the average load, on account of the poorer economy, and if it is worth while to have a boiler house larger than is necessary for the long load hours of the year, it can still carry a short peak even at an uneconomical rating It is usually desirable to use both the boiler and the turbine above the economical capacity for short period peaks in order to obtain a lower annual cost per kilowatt-hour for the year, instead of building the whole plant larger to take care of the peak.

PIPING, VALVES AND FITTINGS FOR HIGH-PRESSURE STEAM SERVICE*

By F. H. Morehead†

INTRODUCTION

I am indeed grateful to the Program Committee for the limitations set on the scope of this paper. It would have been unfortunate indeed had the word "steam" or the term "high-pressure" been omitted.

Even with these limitations it is impossible, in the time allotted, to cover the subject broadly. I have therefore attempted to include very little material of a general character, but have selected and discussed certain details of design, hoping thereby to reduce the paper to an appropriate length.

HISTORICAL

But little has been written on the history of pipe, and still less has been written on the history of valves.

Doubtless, the use of valves began in comparatively early stages of the development of man. It probably dates back even to prehistoric times, and extends up through ancient, medieval, and modern history.

It is believed that man conceived the idea of utilizing materials provided by nature, as well as the power of animals for transportation and for carrying his burdens, long before he recorded the fact. It is known that carrying water in pipes was of very early origin, though history is exceedingly meager as to the means used for controlling and stopping the flow. Nature generously provided a readily available form of pipe in the stem of the bamboo tree which in tropical countries grows to a diameter of five or six inches at the base. This is thought to have been the first form of piping used by man, and to-day it is still used to some extent in China for carrying water short distances.

Hollow logs, pottery tubes, lead pipe, cast-iron pipe, and finally the commercial wrought pipe of modern civilization, followed the use of bamboo. Archæologists have found pottery tubes in Egyptian, Aztec and other excavations. Lead tubes were used extensively in Grecian and Roman civilization. Specimens of lead pipe and bronze

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†Chief Engineer, Walworth Co., Boston.

faucets, very similar to the faucets of the present day, recovered from the ruins of Pompeii and of Herculaneum, after having been buried by the eruption of Mt. Vesuvius in 79, A. D., may be seen in numerous museums.

In the latter part of the eighteenth century, the tireless efforts of James Watt resulted in making the steam engine a practical possibility. It was not until this event that steam assumed any importance. Cocks were introduced for controlling the flow of steam. This type of valve still persists and is quite extensively used at the present time. It is the simplest form of stop-valve in existence, as it has only two major parts. It has the disadvantage that if the plug becomes loosened, or the seat leaks, the fluid contained may escape to the outside of the pipe. It is also difficult to operate and has a great propensity for sticking.

Cast-iron water-pipes were used as early as the middle of the eighteenth century for some purposes. Curiously enough, however, these were objectionable as mains in carrying a potable water-supply on the grounds that they were unhealthful. This in spite of the fact that the water-storage tank and all fittings and valves were usually made of cast-iron.

In the latter part of the eighteenth century and the first part of the nineteenth London water-pipes began to give out, due to increased pressures. It was proposed to substitute pipes of bored stone for the wooden mains because the popular clamor against iron pipes was so formidable. Patents were granted to two or three inventors for stone pipe boring machines, and considerable money was invested in the industry before it was abandoned.

In June, 1820, the first cast-iron water-mains used in Philadelphia were laid. Previous to 1820, mains had been of bored spruce-pine logs, and stop-valves were of the globe type, with a wooden disk and a sliding stem. Fig. 1 shows the type of valve used with these wooden pipes from 1801 to 1844. It is presumed that the valves were mounted with the pressure on top of the disk, because no method was provided for holding the valve closed except the pressure of the water. Neither was there a means for holding the valve open. This was probably accomplished by placing a block under the tee handle.

Boilers employed in connection with this water-supply system are of striking interest in our own age of high steam pressures. Boiler-

shells were rectangular chests nine feet wide and 18 feet long and were made of five-inch white pine planks securely braced on the outside. These wooden boiler-shells, however, did not prove satisfactory in that they could not be kept from leaking. In 1801 the first boiler-shell was replaced by a cast-iron shell, and in 1803 another was superseded by a cast-iron shell of different design. The steam pressure was very slight. Early pumping-engines were called "atmospheric engines" and worked on the condensing principle. Most of the work was done in the engine cylinder at pressures below atmospheric.

The Walworth Company and the steam and hot-water heating industry both had their inception in the formation of a partnership under the firm name of Walworth & Nason. This firm was

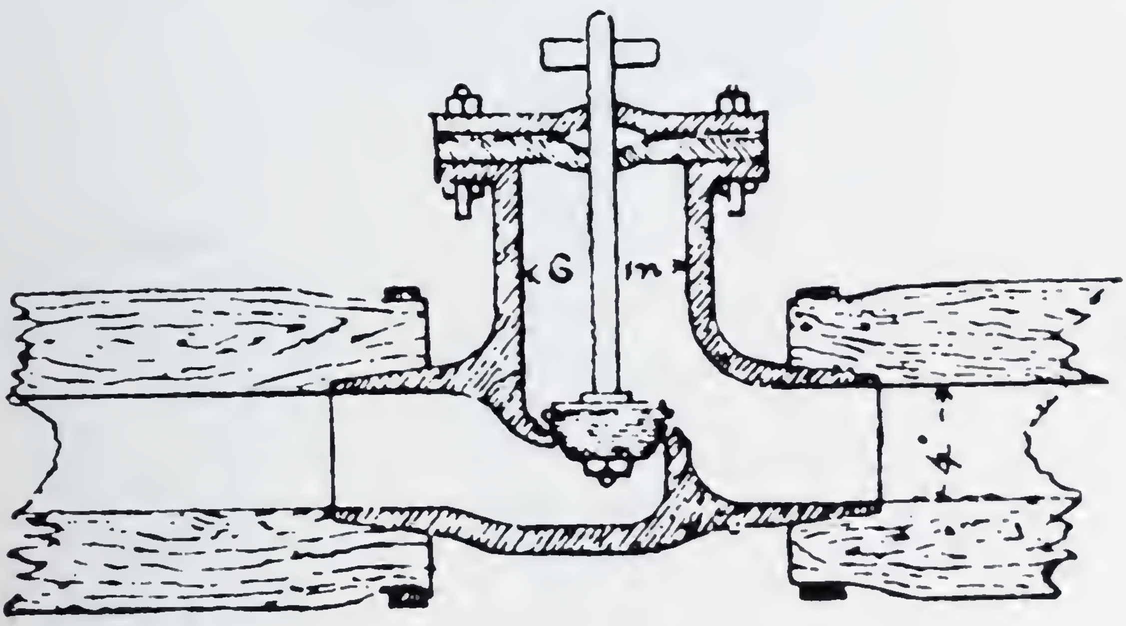

Fig. 1. Valve Used with Wooden Water-Pipes in Philadelphia.

organized in New York in 1841 for the purpose of "warming and ventilating buildings by means of steam and hot water apparatus." Steam was not actually used as a heating medium, however, until three years later. The first partnership consisted of James J. Walworth and Joseph Nason, who were not only close personal friends of long standing, but were brothers-in-law. Mr. Nason's sister was the wife of Mr. Walworth.

The following year the firm of Walworth & Nason moved to Boston, where it continued in business until 1852. Mr. Nason abhorred New England winters, and for this reason withdrew from the firm. He moved to New York and established a similar business under his own name. Mr. Walworth carried on business in Boston

under the firm name of J. J. Walworth & Company. In 1872 the company was incorporated as the Walworth Manufacturing Company.

It is of particular interest that the engineering profession gives credit to Joseph Nason for the development of the globe-valve in practically its present form. This valve was introduced in 1845 and 1846, at the time of Mr. Nason's partnership with Mr. Walworth. In the various concerns manufacturing valves and fittings, which sprang up in New England during the middle and latter part of the last century, many of the leaders received their early training and inspiration in the shops of the Walworth Company.

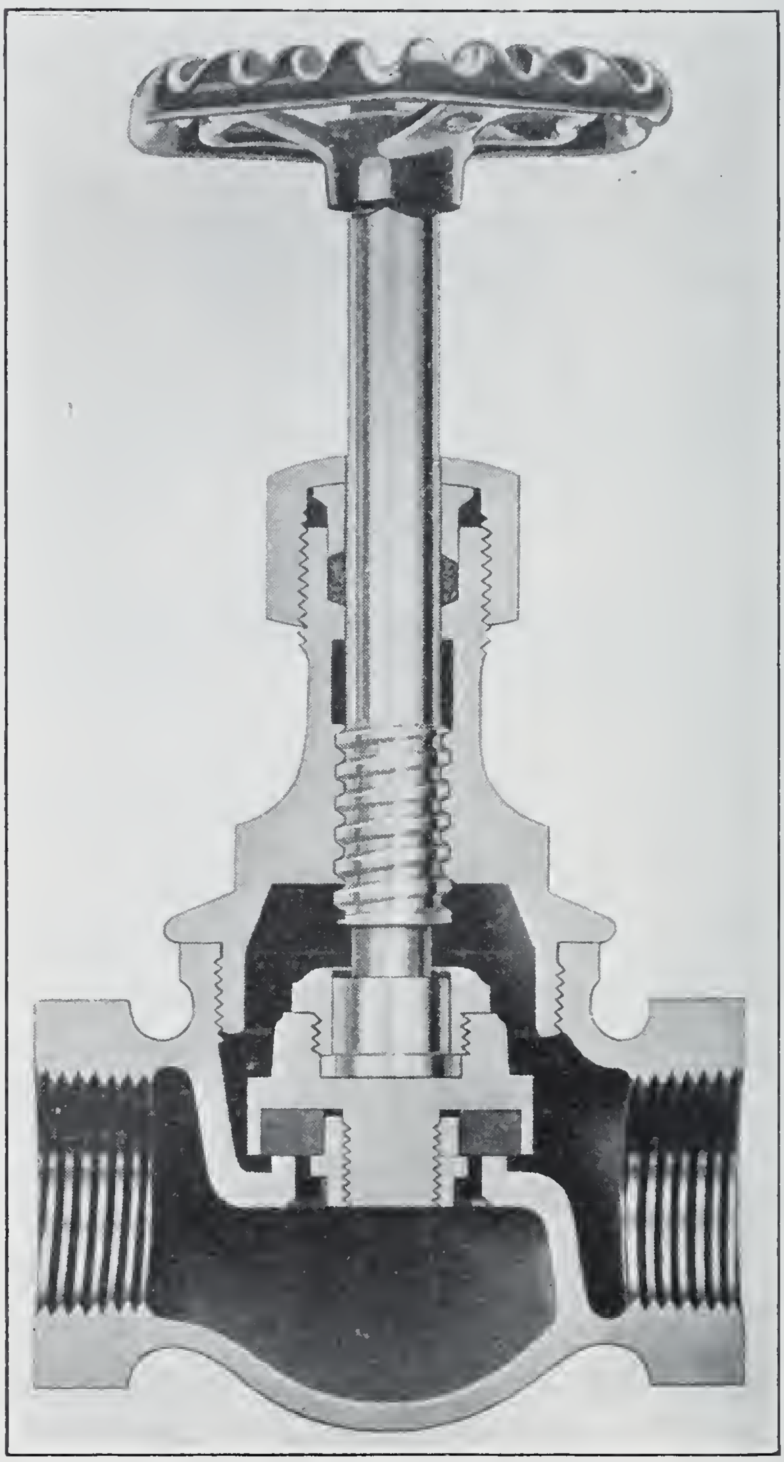

Fig. 2. Jenkins Type Valve.

The valve now known as the Jenkins valve (Fig. 2) was patented by Nathaniel Jenkins, a keen New Englander, in 1868. A feature of his patent was that the disk holder and the valve-seat were so designed and finished that, in case the rubber disk was destroyed, the outer wall of the holder could be brought to a seat outside of the raised seat on which the rubber disk rested, thus stopping the flow. This feature is not now incorporated in the Jenkins type valves. Nathaniel Jenkins exploited his valve very successfully and established such a large demand for it that other manufacturers began to make it when his patent expired.

In 1861, H. G. Ludlow applied his design of the first gate-valve to gas systems, and in 1866 he redesigned it for water service. This valve was and is of the straight-way, double-disk, parallel-seat type. A spreading device located between the disks spreads them apart at the time of closing.

The Peet gate-valve was designed in 1867 by S. J. Peet, of Boston. This valve was of the double-disk type, with conical spreading wedge. This type of valve is still on the market.

In 1867, Z. E. Coffin, also of Boston, brought out another gate-valve which was distinctive in that it was the first double-disk valve to use tapered instead of parallel seats.

In 1869, John C. Chapman brought out the solid wedge type of gate-valve which is so extensively used to-day. This valve was originally made with babbit-metal seats, but these proved unsatisfactory and were later replaced by brass seat rings.

In this connection it is of interest to note that John C. Chapman and Daniel Stillson were cousins and that they were both in the employ of the Walworth Company when they developed their respective inventions of the solid wedge gate-valve and the Stillson wrench.

There has been no fundamental change in the design of globe-valves and gate-valves. The development that has taken place has been directed mainly toward perfecting the old designs and adapting them to the ever-increasing field of application, and to the ever-increasing pressures and temperatures encountered in service. Much constructive work has also been done in improving workmanship and manufacturing processes, which are essential factors in producing high-quality product at a cost within the range of a highly competitive market.

PIPE

The subject of wrought-steel pipe for use at high pressures and temperatures is at the present moment (August 1927) an exceedingly active one with the specification writing bodies.

The American Engineering Standards Committee is now organizing a general tube and pipe committee for consideration of the various specifications on wrought tubular material.

The American Society for Testing Materials has drawn two specifications for steel pipe. Specification A 53 covers welded and seamless pipe for "coiling, bending, flanging and other special purposes." This specification makes no mention of the service in which the pipe is to be placed, and therefore may be assumed to cover material suitable for general application.

During 1923 the American Engineering Standards Committee's Sectional Committee on Standardization of Pipe Flanges and Fittings requested a specification for piping materials for "high-temperature" service. The American Society for Testing Materials at once organized a special committee for this work. The results of this committee's work on pipe are given as "Tentative Specification" A 106 of the American Society for Testing Materials, and will appear in the 1927 "Tentative Standards" of that Society. The specification has been extensively revised since its first appearance as tentative in 1926. This specification now includes a clause to the effect that "all welded pipe shall be given a double welding operation." Tests have been increased in severity to assure the perfection of the weld.

Under the auspices of the Power Piping Society, extensive experiments were performed in order to determine whether or not a double welding operation was desirable for steel pipe intended for flanging and bending. The results of these tests were interpreted to indicate that such double welding was not necessary generally for pipe operating at temperatures and pressures below the extremes specified. Double welding of pipe was, however, considered desirable for extreme service at 250- and 400-pound pressures at 750 degrees F.

Specification A 106-27 T, of the American Society for Testing Materials, includes a table of weights and thicknesses for welded and seamless open-hearth pipe for use at the various pressure steps up to and including 1350 pounds per square inch. Each time that I have occasion to refer to this table I am reminded of Champ Clark's

description of the Missouri mule—"It has neither pride of ancestry nor hope of posterity." The table shows only seamless open-hearth pipe in sizes 1½ inches and smaller.

This table of dimensions and weights indicates that seamless open-hearth pipe of so-called standard weight thicknesses may be used for 400 pounds working pressure in sizes up to 1½ inches. The most unfortunate column is the third one, which is headed "Threads Per Inch." One is led to believe thereby that pipe of this thickness with regular pipe threads might be used for these conditions of service.

Consider, for example, the one-inch size, which is shown by the table to be 0.133 inch thick. The depth of the American Standard thread on this size (11½ threads per inch) is 0.070 inch. The thickness of metal left beneath the root of the last thread which is perfect at the top is 0.063 inch, or just about 1/16 inch. It is difficult to imagine that the men who compiled this table have intended to imply that this type of construction is satisfactory for this service.

The use of butt-welded pipe for extreme service is not permitted under this specification.

During 1926 the United States Department of Commerce called together a representative body of manufacturers and consumers of and dealers in piping material. Manufacturers had long been aware of the fact that certain sizes of pipe were used in exceedingly small quantities as compared with other sizes. It was therefore suggested by the Department of Commerce that these sizes be eliminated from standard lists, and that this elimination affect not only the pipe itself but all accessories such as valves and fittings.

Following up this recommendation, committees functioning under the procedure of the American Engineering Standards Committee have eliminated from all pipe standards the sizes 4½, 7, 9, 11, 15 and 22 inches. A few sizes larger than 24 inches which have appeared in regular lists were also eliminated.

This applies to cast-iron screwed and flanged fittings, to malleable-iron fittings, and to steel fittings and valves. No great hardship will be caused users of this material and stocks and equipment will be much simplified.

Under the procedure of the American Engineering Standards Committee, a sectional committee has been organized to draw up a complete piping code. Several states, notably Ohio and Massachu-

setts, already have piping codes of one kind or another. These codes are, of course, not uniform in their requirements. It is hoped that upon the completion of the piping code the several states may be brought together under a single code. It is the further thought of those engaged in the compilation of the American Piping Code that this code should serve the double purpose of preventing manufacturers from overrating piping material and preventing users from making unsafe installations.

As now contemplated, the code is very broad in its scope. It will cover piping for practically every purpose, including oil, air, ammonia, steam, gas, water and other systems.

PIPE-JOINTS

The pipe-joints used in high-pressure, high-temperature piping systems are of great importance because, no matter how perfect the various units may be, the system as a whole is no better than the joints which bind the units together. Some of the desirable features of a good pipe-joint are:

1. It should have an ample factor of safety under the service conditions to which it is applied.

2. It should be of such design that it can readily be made up in the field so as to assure both a substantial connection and a steam-tight joint.

3. It should be of such design that the pipe-line can be readily lined up in the field so as to provide proper drainage.

4. It should be of such design that the joint can be kept tight under the long-continued action of expansion and contraction stresses and pipe-line vibration.

5. It should be of such design that it can be readily disconnected and reassembled in the field when required.

No matter what type of joint is used, the contact surfaces forming the joint must be held together with a unit pressure exceeding the unit internal pressure multiplied by the area on which it acts. The amount of excess pressure required depends on the character of the contact surfaces. For this reason the elongation in service of the bolts which hold the joints together is a matter of primary importance. The bolts should be as short as possible, and the stretch as well as the

strength should be computed in designing the joint. The deflection of the flanges should also be considered.

Standard flange dimensions and bolting for 250, 400, 600, 900, and 1350 pounds working pressures at 750 degrees F. have been established in Tentative American Standard (B 16e—1927) for Steel Pipe Flanges and Flanged Fittings, issued in June 1927.

Numerous types of joints have been used, but the ones now in common use are either of the vanstone type or some modification of it. This type of joint has the following advantages:

1. The joint is made directly on the inside wall of the pipe, thus eliminating the possibility of a leak at the connection of the pipe to the flange.

2. The flange is loose on the pipe and consequently may be readily rotated during assembly for alinement of bolt holes.

3. The design does not reduce the cross-sectional area of the pipe wall, and when properly made is as strong as the pipe itself.

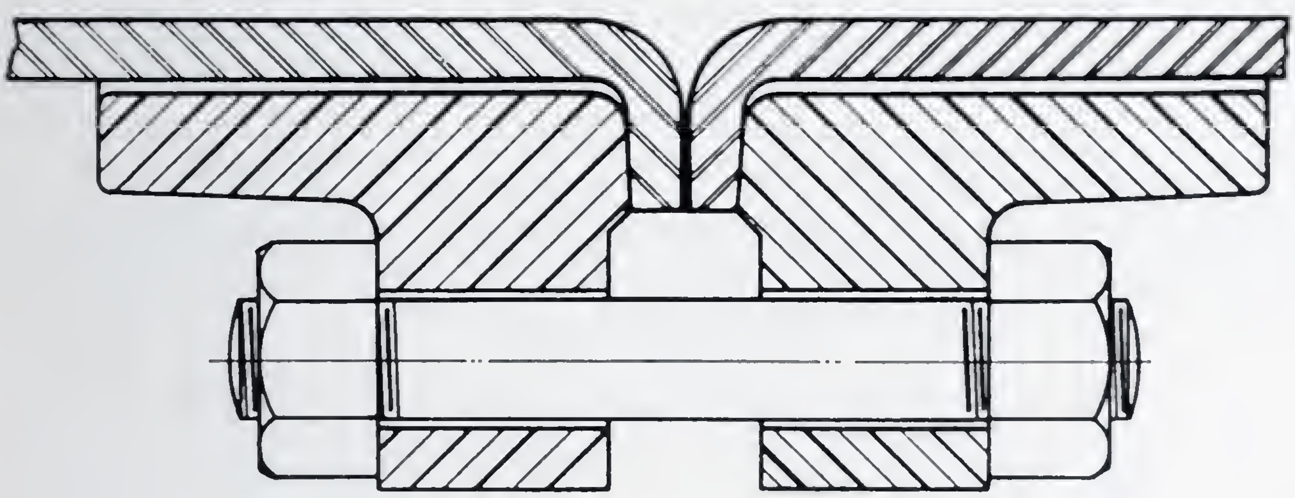

Fig. 3. Vanstone Joint.

Fig. 3 shows the typical design of a round-cornered vanstone joint which is extensively used.

The square-cornered vanstone joint is preferred by some users because it eliminates the small pocket formed by the round corners of the joint previously shown. It should be borne in mind, however, that in producing this type of joint the material in the pipe wall is subjected to a more drastic forging and upsetting process, and unless the forging temperature is properly controlled to avoid both overheating and cold working there is considerable danger of introducing a coarse grain structure, severe internal stresses and incipient cracks.

Annealing will improve bad grain structure and relieve internal stresses, but will not, of course, correct the last mentioned defect.

A square-cornered vanstone joint of the male and female type is sometimes used. This joint insures accurate alinement, automatically centers the gasket, and protects it from blowing out. Some fabricators produce the vanstone lap by rolling the pipe directly into the flange. This type of joint can not be made in that manner. It requires that the lap be rolled against a die.

There is also a tapered vanstone joint which is rolled into a tapered flange so as to provide additional resistance to pulling the pipe out of the flange in service. A test of a six-inch pipe with a wall three-eighths of an inch thick, recorded in the 1926 report of the Prime Movers Committee of the National Electric Light Association, indicates that when the lap was removed the tapered seat developed a resistance to pulling out of the flange equivalent to 14 per cent. of the longitudinal strength of the pipe. On account of the pipe being rolled into the flange this type of joint does not permit the ready rotation of the flange for the purpose of matching the bolt holes. It also forms a larger pocket in the pipe-line than the conventional round-cornered vanstone joint.

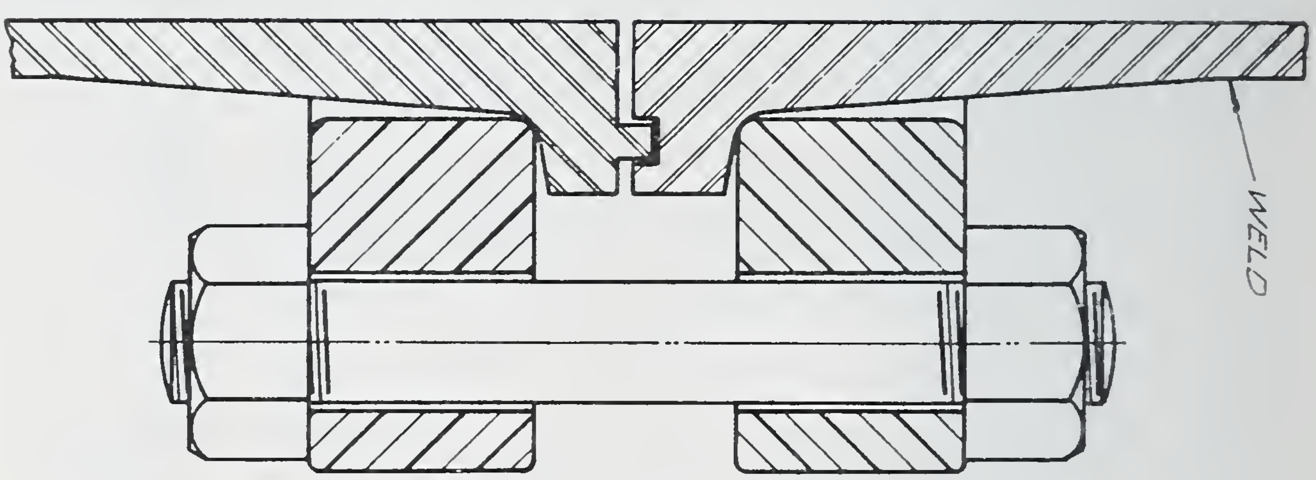

Fig. 4. Kellogg Joint.

Fig. 4 shows a tongue-and-groove type of vanstone joint in which a higher gasket pressure is secured due to the narrow gasket used. This type of joint assures accurate alinement and prevents blowing out of the gasket. As the flanges are not provided with hubs their resistance to deflection appears to be somewhat less than the conventional vanstone high-hub flange.

Another type of joint successfully used for joining flanges is the Kell-Raph joint, in which the gasket is replaced by a copper-plated, forged-steel ring of rectangular cross-section, fitting into recesses in the flanges. This type of ring has the advantage of a soft copper contact surface backed up by forged steel so that it does not flow under the enormous pressures to which it is subjected.

The H. L. Doherty ring joint is a somewhat similar type of joint in which the forged-steel ring fits into tapered grooves in the flanges. The ring is also recessed on both faces in order to give the contact surfaces a spring-like action so as to keep the joint tight under slight elongation of the flange bolts.

The Midwest joint is extensively used in the Texas oil fields on high-temperature lines for joining flanges. It is also used in steam lines to a somewhat less extent. In this design a forged ring having ball-shaped contact surfaces is used between the flanges, and this ring is sometimes made an integral part of one of the flanges. For joining two pipes, or a pipe to a fitting, the end of the pipe is rolled into a ball seat in the flange and the joint is made between the pipe and the ball-shaped contact surface of the forged ring.

The Standard Oil Company also has a special type of joint which it uses extensively for joining flanges. In this design, the forged ring which replaces the gasket is of rectangular cross-section with generously rounded corners fitting into tapered recesses in the flanges.

An interesting joint was used in the now famous Langerbrugge station near Ghent, Belgium. This station operates at about 710 pounds and at 840 degrees at the turbine throttle. The pipe has a straight thread and is rolled into the flange after screwing on. The gasket is of mild steel, accurately machined all over with V-shaped concentric grooves at the contact surface. Bolts are accurately turned and are fitted into reamed holes in the flanges. The contour of the bolts is interesting and will be discussed later.

The proportions of this joint are radically different from those of the American Standard. The flanges are smaller in diameter and relatively much thicker than those of the 900-pound standard. Also, the bolt circle is reduced to the smallest possible dimension, even to the point where there is no fillet.

Fig. 5 illustrates the "Sargol" type of joint. The flanges are smooth faced and the projecting lips are welded together after erec-

tion. This joint has the very laudable quality of using no gasket. Certain features of it are discussed later.

The finish of the contact or gasket surfaces is a matter on which specifying engineers do not agree. On certain of the joints previously described a very smooth finish is obviously required. Where gaskets are used this smooth finish is sometimes replaced by a series of concentric or spiral grooves. These grooves are assigned various shapes and sizes, depending partly on the nature of the gasket used and partly on the ideas of the designing engineer. Such grooves very materially reduce the gasket pressure necessary to prevent blow-outs. Generally speaking, they should be small (not larger than 1/32-inch pitch) where metallic gaskets are used, and may be increased slightly as to size and pitch where asbestos or other composition gaskets are used. The shape of the grooves is of little importance, provided their

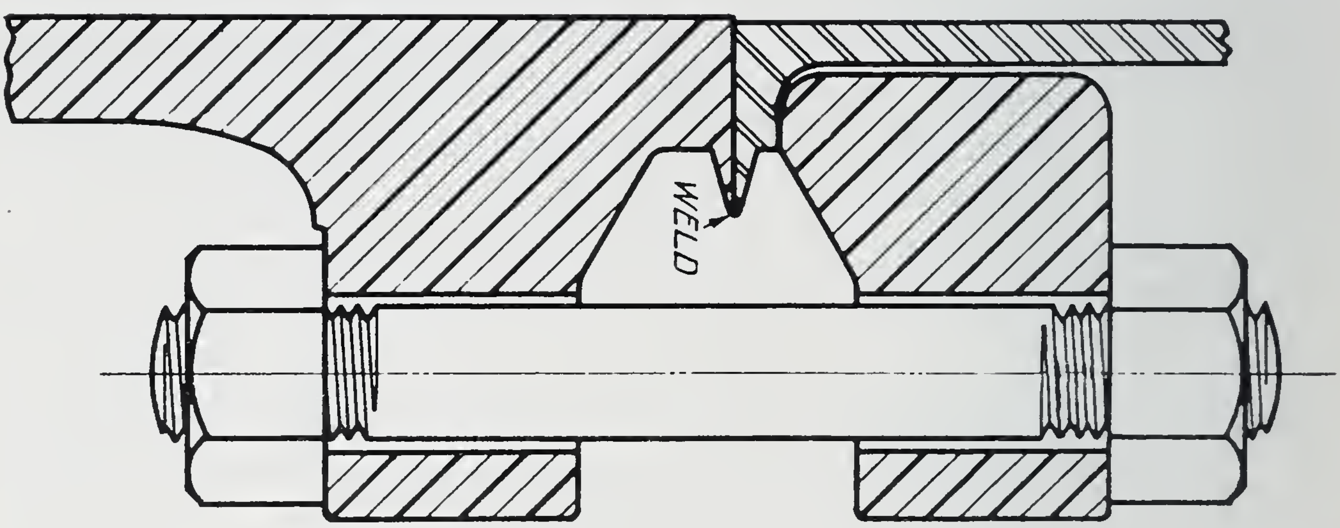

Fig. 5. "Sargol" Joint.

size is suited to the material used for gaskets; neither is it important whether the grooves are concentric or spiral.

A somewhat undesirable feature of all pipe-joints that interlock, like the male and female, tongue and groove, etc., is that the units must be shifted longitudinally when the joint is assembled or disconnected. Where rigid connections do not permit springing the joints apart for assembling and disconnecting, this type of joint presents serious difficulties and in some cases can not be used.

The American Standard recognizes six types of joint as follows: vanstone, raised face, large male and female, small male and female, large tongue and groove, and small tongue and groove. Manufac-

turers of this class of material have adopted a standard practice to the effect that the large male facing shall be regular practice on all material for stock. The large male face is of the same diameter as the raised face. It is ¼ inch high on all sizes of valves and fittings for all pressures. The corner at the junction of the male face and the flange face is square. The corner at the junction of the raised face and the face of the flange may be rounded. This will not permit the raised face to be used as a male face.

The raised face and large male face contemplate moderate gasket pressures and may be assumed to cover satisfactory joints when asbestos sheet gaskets are used. These large facings are probably not satisfactory if metallic gaskets are employed, because a metallic gasket requires a much higher unit gasket pressure to prevent leaks and the end flange boltings are not sufficiently heavy to create such pressure over so large an area. When metallic gaskets are used, small male-and-female, or large or small tongue-and-groove joints, should be employed if the American Standard is followed. The use of the small male-and-female joint contemplates a straight pipe thread of maximum diameter—that is, the diameter over the crests of the threads is equal to the outside diameter of the pipe. In using this joint for connecting pipe to fitting, it is customary to use the end of the pipe as the male member of the joint. This is accomplished by screwing the pipe through the flange and by turning off the projecting threads to the root diameter. The female portion of the joint is made in the fitting or valve. For connecting pipe to pipe, the gasket recess in the female flange presents a threaded face to the edge of the gasket and therefore does not give the gasket the same support as is the case with other types of female facings.

BOLTS AND NUTS

The question of the most suitable design and materials for bolts and nuts to be used in high-pressure, high-temperature flanged joints has been the subject of much investigation and discussion during the past few years.

Before the era of present-day temperatures and pressures, wrought-iron and soft steel were considered ideal for bolt material because of their high ductility. It was found, however, that such bolts, when subjected to high temperature and stress for long periods, became seriously weakened so that failures occurred under loads which

appeared to be well within the safe load-carrying capacity of the bolts. The results of more recent studies have shown that while bolt material should have sufficient ductility to insure against sudden failures without warning, high elastic limit, impact strength, endurance limit and resistance to creep at high temperatures are much more desirable qualities than high ductility.

If the bolts are to hold the joint surfaces together with sufficient pressure to prevent leakage and blowing out of the gasket under all conditions, they should never be stressed beyond their elastic limit. Should the stress exceed the elastic limit of the material the bolt would be permanently stretched and, when retightened, to stop the leak, the cycle of stretching and tightening would be repeated until the bolt finally failed.

Shocks due to water-hammer or the sudden closing of a valve demand high impact strength, while pipe-line vibration due to high velocities of flow, and repeated stresses due to expansion and contraction, require a high endurance limit or resistance to fatigue. Under extremely high working temperatures, however, it appears that the creep effect of long-sustained loads is more serious than is the effect of repeated stresses having a short duration. For these reasons heat-treated alloy steel of high tensile strength is now considered essential for bolt material for such service, and the new Tentative American Standard for steel pipe flanges and flanged fittings specifies material equal to standard specification A 96 of the American Society for Testing Materials. This standard recognizes three grades of material and specifies physical and chemical requirements as follows:

Class "A"

Tensile strength, minimum	95,000 pounds per square inch
Yield-point, minimum	70,000 pounds per square inch
Elongation in two inches, minimum	20 per cent.
Reduction of area, minimum	50 per cent.
Phosphorus, maximum	0.05 per cent.*
Sulphur, maximum	0.05 per cent.

Class "B"

Tensile strength, minimum	105,000 pounds per square inch
Yield-point, minimum	80,000 pounds per square inch
Elongation in two inches, minimum	20 per cent.
Reduction of area, minimum	50 per cent.
Phosphorus, maximum	0.05 per cent.*
Sulphur, maximum	0.05 per cent.

Class "C"

Tensile strength, minimum	125,000 pounds per square inch
Yield-point, minimum	105,000 pounds per square inch
Elongation in two inches, minimum	16 per cent.
Reduction of area, minimum	50 per cent.
Phosphorus, maximum	0.05 per cent.*
Sulphur, maximum	0.05 per cent.

For extreme conditions the Class "C" bolting material having a minimum tensile strength of 125,000 pounds per square inch and yield-point of 105,000 pounds per square inch is ordinarily used.

Carbon-steel nuts are specified in the American Standard, but case-hardened carbon-steel nuts, heat-treated carbon-steel nuts and alloy-steel nuts also have been used in some cases. Without question, alloy-steel nuts are superior to all others. Trouble has resulted in some instances from galling and seizing so that nuts could not be tightened after some months of service at high temperature and the studs could be removed only by cutting with a torch. These difficulties have been largely overcome by careful control of the materials used and of the finish and fits of threads.

In this connection it should be borne in mind that special properties imparted to metals by heat treatment may be subsequently altered to a material extent by the heat imposed in service unless the final drawing of the heat treatment is well above the working temperature of the material.

Studs with a nut at each end are recommended in Tentative American Standard B 16e, because the drastic forging operation involved in the heading of the bolt has in a number of instances resulted in failures due to weakness at the junction of the bolt head and the shank. It is standard practice to furnish the studs with a normal length of thread at each end, but in some cases where an additional factor of safety is desired the studs are threaded for their entire length so that the stretch will be uniformly distributed instead of being concentrated in the short, threaded portion under stress, where the cross-sectional area is reduced and the unit stress correspondingly

*The phosphorus requirement of 0.05 per cent. for alloy steel bolt material agrees with the limits in American Society for Testing Materials specification A 96-26 specified for "check analysis" on finished material. For the sake of uniformity in giving the phosphorus content for castings, bolt material and forged-steel flanges, the 0.05 per cent. requirement is retained instead of the "mill" or "ladle analysis" requirement of 0.04 per cent. as given in the specification of the American Society for Testing Materials.

increased. In other cases the middle portion of the stud is turned down to the root diameter of the thread.

The methods used for computing the strength of bolts for flanged joints are not entirely uniform. This is not surprising because of the numerous factors which affect the stresses in the bolts. Some of these factors are:

1. The initial stresses of combined torsion and tension set up in the bolts when the flanges are assembled.

The initial stress set up when the flanges are assembled is not readily computed because the unit pressure on the joint surface, required to prevent leakage and blowing out of the gasket, varies considerably with the type of joint and the kind of gasket used. For joints using metal gaskets having a narrow contact surface a unit gasket pressure of 12 times the unit internal pressure is ordinarily used for purposes of computation. This figure was derived from experimental data on joints of this type. The initial bolt stress and gasket pressure actually set up in assembling joints in the field is also likely to vary considerably, even though standardized wrenches and methods of tightening are used. Striking the wrench with a hammer while the nut is being tightened is known to increase the tensile stress in the bolt from 30 to 150 per cent. under various conditions. Because of this uncertainty in the gasket pressure required, and the unavoidable variations of the stress actually set up by tightening the nuts, the initial stress in the bolts can not be accurately computed and must be taken care of by using an ample factor of safety.

2. The additional stress in the bolts due to internal working pressure.

This stress is readily computed, and in high-pressure joints is a large part of the total bolt stress.

3. The additional stress in the bolts due to pipe-line temperature changes.

This stress is relatively small compared to the total stress in the bolts, and it is usually taken care of in the factor of safety.

4. Variations of stress in bolts due to difference in the thermal expansion of the material between the bolt heads and that in the bolt itself.

These variations are not readily computed. In joints of such design that the material between the heads of the bolts is considerably hotter than the bolt itself, when the joint is in service, the stress in the bolt may be materially increased by the difference in expansion. As this effect can not be accurately computed, it is customary to cover it by a proper allowance in the factor of safety. In some cases the flanges are covered and in others they are left bare. This may change the temperature of the bolts by several hundred degrees.

5. Reduction in safe working stress in bolts due to elevated temperature, vibration, shock, etc.

This reduction is taken care of by knowing definitely the physical properties at elevated temperatures of the bolt material used.

It is readily seen that items two and five are the only ones susceptible of accurate computation. The initial stress in the bolts is known to be quite large, particularly in the larger sizes of joints, and can not be ignored even though it is not readily susceptible of computation. At first thought it might seem that in an actual joint this stress is added in full to the bolt stress caused by the internal pressure; however, this could happen only if the gasket had such a low modulus of elasticity that it would act like a spring, expanding as the bolt elongated under additional load and continuing to exert practically the full initial pressure on the joint surface. Desirable as this would be in service, no such gasket material suitable for high-temperature service has ever been discovered.

The method set up in Tentative American Standard B 16e is to cover the initial stress by adding the entire gasket area to the area over which the internal pressure acts and by using a low allowable working stress in the bolts. Both of these provisions give an added factor of safety. The formula in Fig. 7 was used for the small tongue-and-groove fittings.

Fig. 6 and 7 show the bolt stress in American Standard 400-, 600-, 900-, and 1350-pound flanges as computed by these two methods. While a great deal more might be said on the subject of bolts and nuts, it is hoped that the main points have been covered sufficiently to show that their importance in a piping system is fully realized and to indicate the methods used in providing safe and dependable joints.

BOLT STRESSES BY FORMULA—

$$\frac{\text{Area to outside of face}}{\text{Area of bolts}} \times \text{Pressure} = \text{Stress}$$

Pipe Size	Dia. R.F.	Area	400 Bolts	400 Area	400 Stress	600 Bolts	600 Area	600 Stress	900 Bolts	900 Area	900 Stress	1350 Bolts	1350 Area	1350 Stress
1/2	1 3/8	1.485				4-1/2	.502	1775						
3/4	1 11/16	2.237				4-5/8	.808	1661						
1	2	3.142				4-5/8	.808	2338				4-7/8	1.68	2530
1 1/4	2	4.909				4-5/8	.808	3658				4-7/8	1.68	3350
1 1/2	2 7/8	6.492				4-3/4	1.21	3220				4-1	2.20	3980
2	3 5/8	10.32				8-5/8	1.62	3830				8-7/8	3.36	4160
2 1/2	4 1/8	13.36				8-3/4	2.42	3315				8-1	4.40	4100
3	5	19.64				8-3/4	2.42	4875	8-7/8	3.36	5260	8-1 1/8	5.82	4560
3 1/2	5 1/2	23.76				8-7/8	3.36	4240	8-1	4.40	4850	8-1 1/8	5.82	5510
4	6 3/16	31.92	8-7/8	3.36	3790	8-7/8	3.36	5690	8-1 1/8	5.82	4930	8-1 1/4	7.43	5730
4 1/2	6 3/4	35.79	8-7/8	3.36	4260	8-1	4.40	4880	8-1 1/8	5.82	5540	8-1 3/8	9.23	5230
5	7 5/16	42.72	8-7/8	3.36	5100	8-1	4.40	5830	8-1 1/4	7.43	5470	8-1 1/2	11.22	5140
6	8 1/2	56.75	12-7/8	5.04	4500	12-1	6.60	5260	12-1 1/8	8.72	5850	12-1 3/8	13.84	5530
7	9 5/8	72.76	12-1	6.60	4420	12-1 1/8	8.72	5010	12-1 1/4	11.14	5880	12-1 1/2	16.84	5830
8	10 5/8	88.66	12-1	6.60	5370	12-1 1/8	8.72	6110	12-1 3/8	13.84	5760	12-1 5/8	20.15	5840
9	11 5/8	106.1	12-1 1/8	8.72	4860	16-1 1/8	11.63	5450	16-1 3/8	18.46	5180			
10	12 3/4	127.7	16-1 1/8	11.63	4390	16-1 1/4	14.85	5150	16-1 3/8	18.46	6220	12-1 7/8	27.6	6250
12	15	179.7	16-1 1/4	14.85	4840	20-1 1/4	18.56	5820	20-1 3/8	23.1	6990	16-1 7/8	36.8	6580
14	16 1/4	207.4	20-1 1/4	18.56	4460	20-1 3/8	23.1	5380	20-1 1/2	28.1	6650			
15	17 1/4	233.7	20-1 1/4	18.56	5040	20-1 3/8	23.1	6070	20-1 5/8	33.6	6270			
16	18 1/2	268.8	20-1 3/8	23.1	4670	20-1 1/2	28.1	5760	20-1 5/8	33.6	7200			
17	19 3/4	306.4												
18	21	363.1	24-1 3/8	27.7	5240	20-1 5/8	33.6	6480	20-1 7/8	46.1	7090			
20	23	415.5	24-1 1/2	33.7	4940	24-1 5/8	40.3	6180	20-2	53.0	7050			
22	25 1/4	500.7	24-1 5/8	40.3	5030									
24	27 1/4	583.2	24-1 3/4	47.5	4920	24-1 7/8	55.3	6330	20-2 1/2	65.3	6110			

Fig. 6. Formula 1.

Bolt Stresses by Formula—

$$S = \frac{A + 12B}{C} P$$

A = Area to inside of small gasket

B = Area of small gasket

C = Area of bolts

P = Pressure

Pipe Size	Area Tongue O.D.	A	B	12B	Total	P = 400 Lbs. Bolts	C	S	P = 600 Lbs. Bolts	C	S	P = 900 Lbs. Bolts	C	S	P = 1350 Lbs. Bolts	C	S
1/2	1.485	.785	.700	8.40	9.185				4-1/2	.502	10980						
3/4	2.237	1.353	.884	10.60	11.95				4-5/8	.808	6880						
1	2.761	1.767	.994	11.92	13.69				4-5/8	.808	10160				4-7/8	1.68	11000
1 1/4	3.976	2.761	1.215	14.58	17.34				4-5/8	.808	12880				4-7/8	1.68	13940
1 1/2	4.909	3.547	1.362	16.35	19.90				4-3/4	1.21	9871				4-1	2.20	12000
2	8.296	6.492	1.804	21.65	28.14				8-5/8	1.62	10420				8-7/8	3.36	11300
2 1/2	11.05	8.946	2.104	25.25	34.20				8-3/4	2.42	8490				8-1	4.40	10500
3	16.80	14.19	2.61	31.30	45.50				8-3/4	2.42	11280	8-7/8	3.36	12200	8-1 1/8	5.82	10540
3 1/2	20.63	17.73	2.90	34.80	52.50				8-7/8	3.36	9370	8-1	4.40	10720	8-1 1/8	5.82	12180
4	25.41	21.14	4.27	51.25	72.40	8-7/8	3.36	8620	8-7/8	3.36	12920	8-1 1/8	5.82	11180	8-1 1/4	7.43	13150
4 1/2	30.68	25.97	4.71	56.50	82.50	8-7/8	3.36	9820	8-1	4.40	11240	8-1 1/8	5.82	12750	8-1 3/8	9.73	12060
5	36.50	31.00	5.50	66.00	97.00	8-7/8	3.36	11540	8-1	4.40	13200	8-1 1/4	7.43	11750	8-1 1/2	11.22	11650
6	50.27	44.18	6.09	73.10	117.30	12-7/8	5.04	9320	12-1	6.60	10660	12-1 1/8	8.72	12100	12-1 3/8	13.84	11440
7	63.62	55.09	8.53	102.40	157.50	12-1	6.60	9550	12-1 1/8	8.72	10830	12-1 1/4	11.14	12,710	12-1 1/2	16.84	12640
8	78.54	69.03	9.51	114.10	183.10	12-1	6.60	11100	12-1 1/8	8.72	12600	12-1 3/8	13.84	11910	12-1 5/8	20.15	12280
9	95.03	84.54	11.51	138.10	227.60	12-1 1/8	8.72	10200	16-1 1/8	11.63	11500	16-1 3/8	18.46	10860			
10	113.1	99.40	13.70	164.40	263.80	16-1 1/8	11.63	9070	16-1 1/4	14.85	10660	16-1 3/8	18.46	12850	12-1 7/8	27.6	12900
12	159.5	143.1	16.40	196.8	339.9	16-1 1/4	14.85	9160	20-1 1/4	18.56	11000	20-1 3/8	23.1	13250	16-1 7/8	36.8	12280
14.00	188.7	170.9	17.80	213.5	384.4	20-1 1/4	18.56	8290	20-1 3/8	23.1	9980	20-1 1/2	28.1	12310			
15.00	213.8	194.8	19.00	228.0	422.8	20-1 1/4	18.56	9120	20-1 3/8	23.1	11000	20-1 5/8	33.6	11340			
16.00	244.0	220.4	23.60	283.0	503.4	20-1 3/8	23.1	8720	20-1 1/2	28.1	10750	20-1 5/8	33.6	13500			
17.00	279.8	254.5	25.30	304.0	558.5												
18.00	318.1	291.0	27.10	325.0	616.0	24-1 3/8	27.7	8900	20-1 5/8	33.6	11000	20-1 7/8	46.1	12030			
20.00	380.1	346.4	33.70	405.0	751.4	24-1 1/2	33.7	8920	24-1 3/8	40.3	11130	20-2	53.0	12760			
22.00	461.9	424.6	37.30	447.5	872.1	24-1 5/8	40.3	8650									
24.00	541.2	500.7	40.50	486.0	986.7	24-1 3/4	47.5	8310	24-1 7/8	55.3	10700	20-2 1/4	85.8	10350			

Fig. 7. Formula 2.

STEEL CASTINGS

There are a few basic principles in steel foundry practice that should ever be in the minds of those who design steel castings. Briefly, they are these:

1. Molten steel is introduced into the mold by gravity only.

2. Steel in cooling and solidifying shrinks approximately ¼ inch per foot in its linear dimensions, and approximately six per cent. in volume.

3. That portion of the molten steel which is in contact with the mold cools and solidifies first, and solidification progresses from the surface toward the center of the section at a decreasing rate.

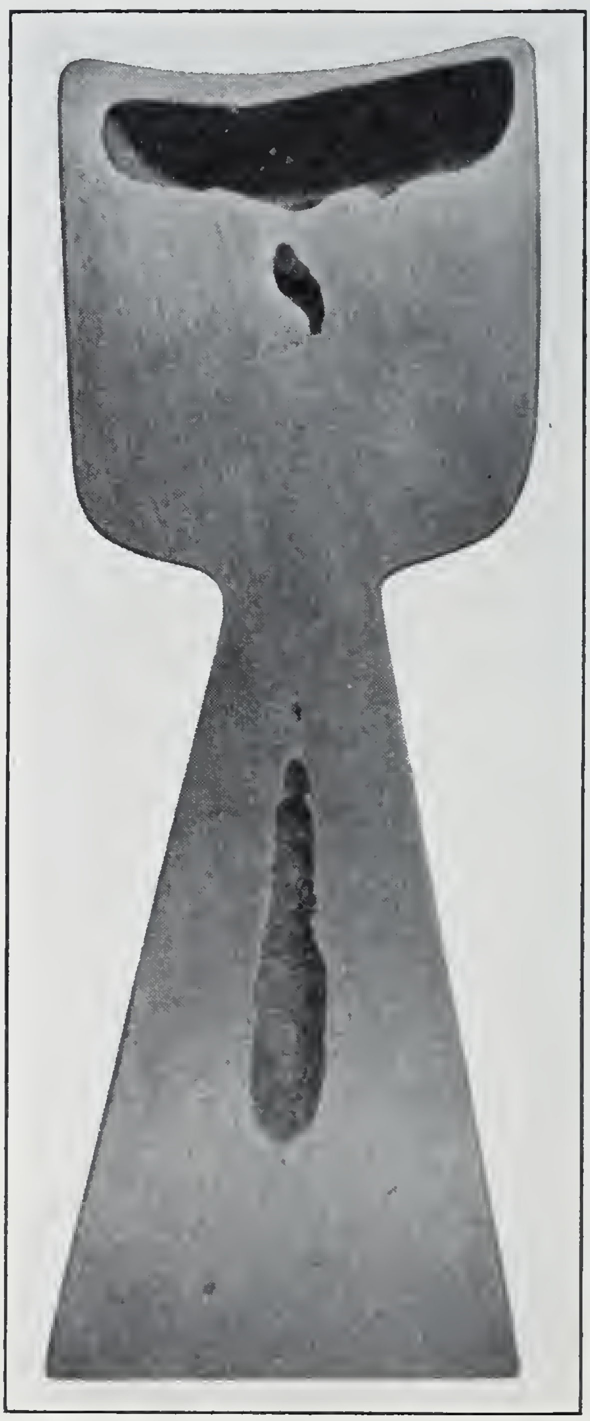

Fig. 8. Steel Casting Improperly Headed.

4. Core and molding sands contain more or less material which is gasified at the temperature of molten steel.

If these four conditions are considered and provided for, the production of steel castings of uniformly good quality will result, assuming, of course, that good steel is to be had from the melting furnace.

In Fig. 8, three of these conditions have been lost sight of. The head is obviously of liberal size, but is attached to the casting by too small a neck. The neck solidified before the casting. That part of the steel in the casting which remained molten after the neck had frozen solidified later and a cavity resulted.

Fig. 9. Steel Casting Properly Headed.

The same piece is readily produced by reversing the position of the casting and greatly increasing the size of the connecting member. The head was substantially reduced in size and a saving in metal resulted. See Fig. 9.

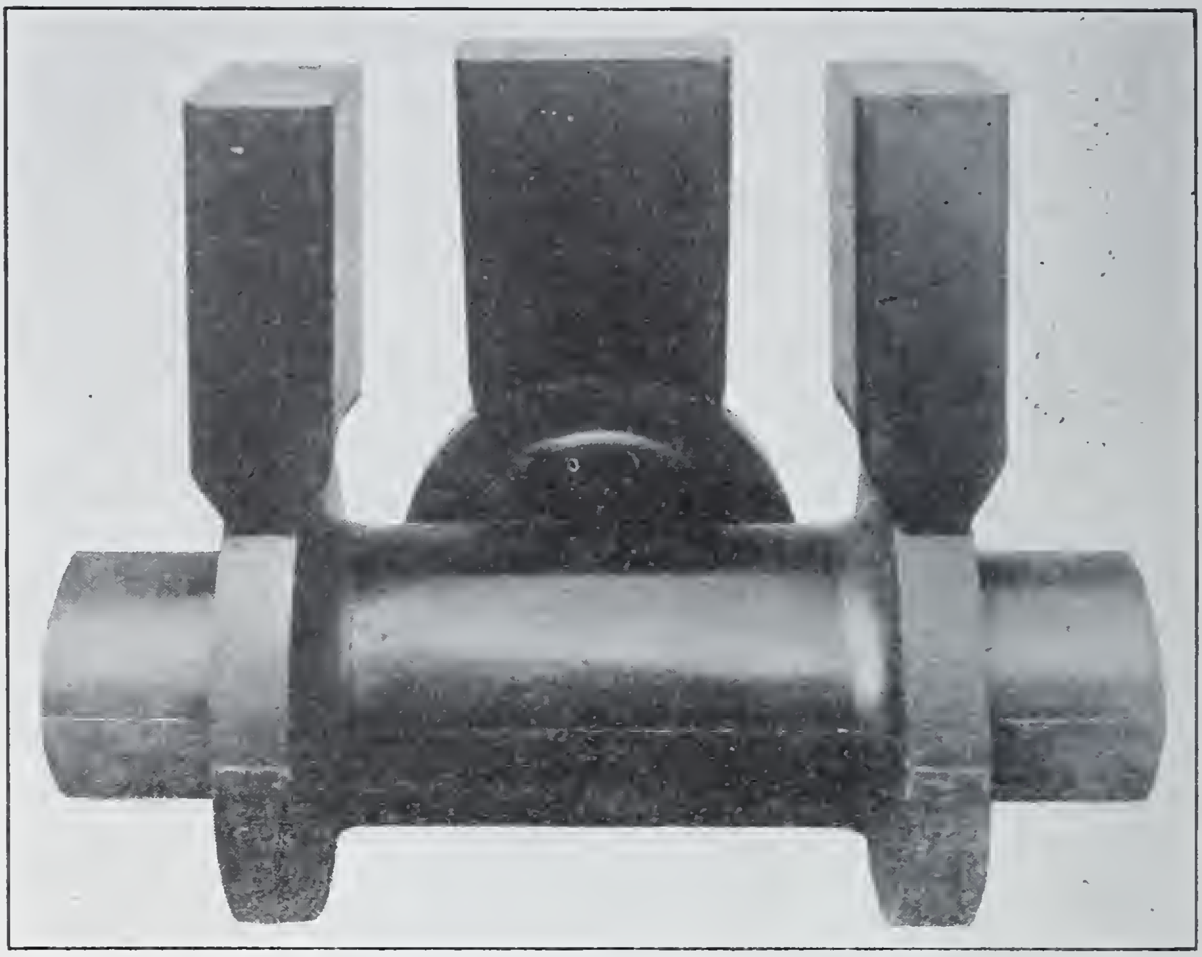

Fig. 10. Pattern for Steel Flanged Tee.

In Fig. 10 is shown a pattern for a flanged steel tee with standardized heads attached. The heads are thicker than the flanges and the connection of head to flange is very short. The proximity of this large mass of molten metal keeps the upper portion of the flange molten until the lower portion has solidified. The lower part is fed by the upper part, and the upper part is in turn fed by the head.

Fig. 11 shows what happened to the head itself. The cavity in the head resulted from the steel flowing down to fill the flange. This shows clearly how the shrinkage in volume may be thrown into a portion of the casting, which is later cut off and discarded.

The linear shrinkage is our next consideration. In flanged steel fittings this is an exceedingly troublesome condition to overcome. A 12-inch flanged tee for 400 pounds working steam pressure is 30 inches face to face. After solidification, it is therefore 3/8 inch shorter

than the mold in which it was cast. In shrinking, the body of the tee must be strong enough to crush the mold back of the flanges. If the mold resists beyond the strength of the steel, cracks will result either in the body section or in the fillet back of the flange.

There are several methods of accomplishing this breakdown of the mold at the proper time. That portion of the mold immediately behind the flanges is rammed up soft so that it will yield easily. A binder is used which quickly disintegrates at high temperature, but will stand long enough to withstand the head of molten metal for a sufficient length of time to allow it to stand alone. In large molds open spaces are sometimes left behind the flanges to insure the mold crushing when the metal solidifies and shrinks. In cored castings the same method is used in the core. The compound used allows the core to crumble at the proper time so that the casting is permitted to shrink.

Fig. 11. Casting for Steel Flanged Tee.

SPECIAL CASTINGS

The problems involved in the development of foundry equipment are sometimes difficult and expensive to solve. If a casting is to be made in quantity, the preliminary work may be assumed to bring returns. If, however, only a small number of castings are required, the cost of this work may greatly exceed the value of the casting. The avoidance of special castings therefore is strongly urged.

WELDING

The power-plant designer should keep in mind the rapid progress now being made in the art of welding. The atomic hydrogen process, the shielded arc process, and the development of welding rods of materials other than pure iron, are all tending to improve the certainty of good welds. The further development of standardized methods for training welders and for testing their work also tends to produce more reliable work. For reasons previously outlined, certain shapes may not be produced in cast-steel. Such pieces should be considered from the standpoint of welding by one of the several excellent methods now available.

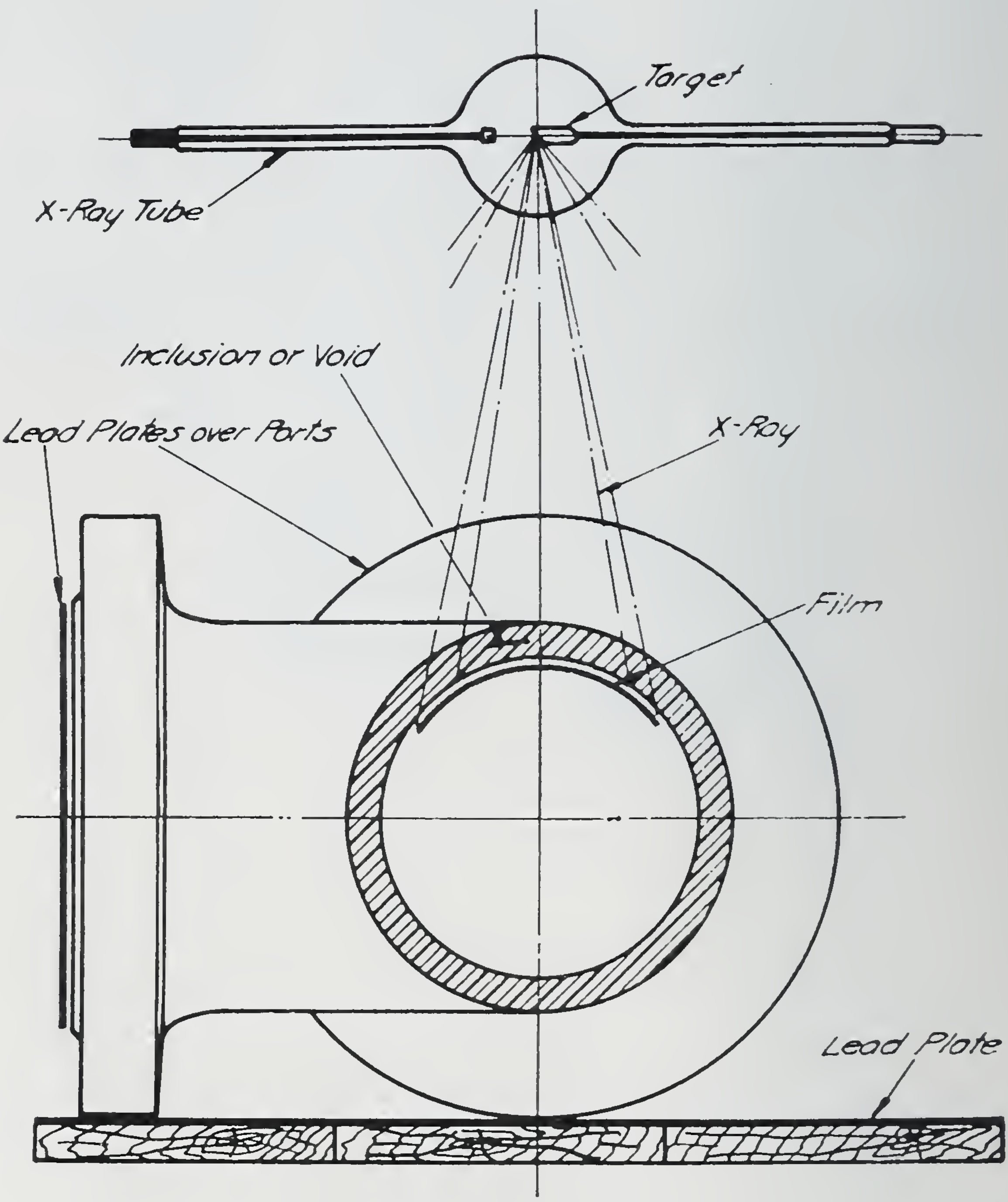

Fig. 12. Making X-Ray Exposure.

X-RAY

One method which has been used extensively in the development of equipment and methods for the production of sound steel castings is the X-ray, or shadowgraph. The use of X-rays for medical work is so familiar to most of us that only a brief description of the method employed in taking X-ray exposures will be given here.

The X-ray apparatus used for this work is exactly like the medical apparatus except that much higher voltages are used than are necessary to penetrate flesh and bone.

Fig. 12 is taken from a line drawing showing the method of making the X-ray exposure. A large Coolidge tube of the usual type is used. The impressed direct-current voltage on this tube may be as high as 280,000 volts. This is a sufficiently high voltage to penetrate

Fig. 13. X-Ray Room, Watertown Arsenal.

three inches of steel. The entire apparatus is located in a lead-lined room, with an automatic switch attached to the door which prevents illumination of the tube while the door is open. Observations of the

tube and specimen during the X-ray exposure are made through a periscope which has double reflectors of lead glass.

The voids, inclusions and all variations in the density or thickness of the metal affect the degree of exposure and show very clearly on the film.

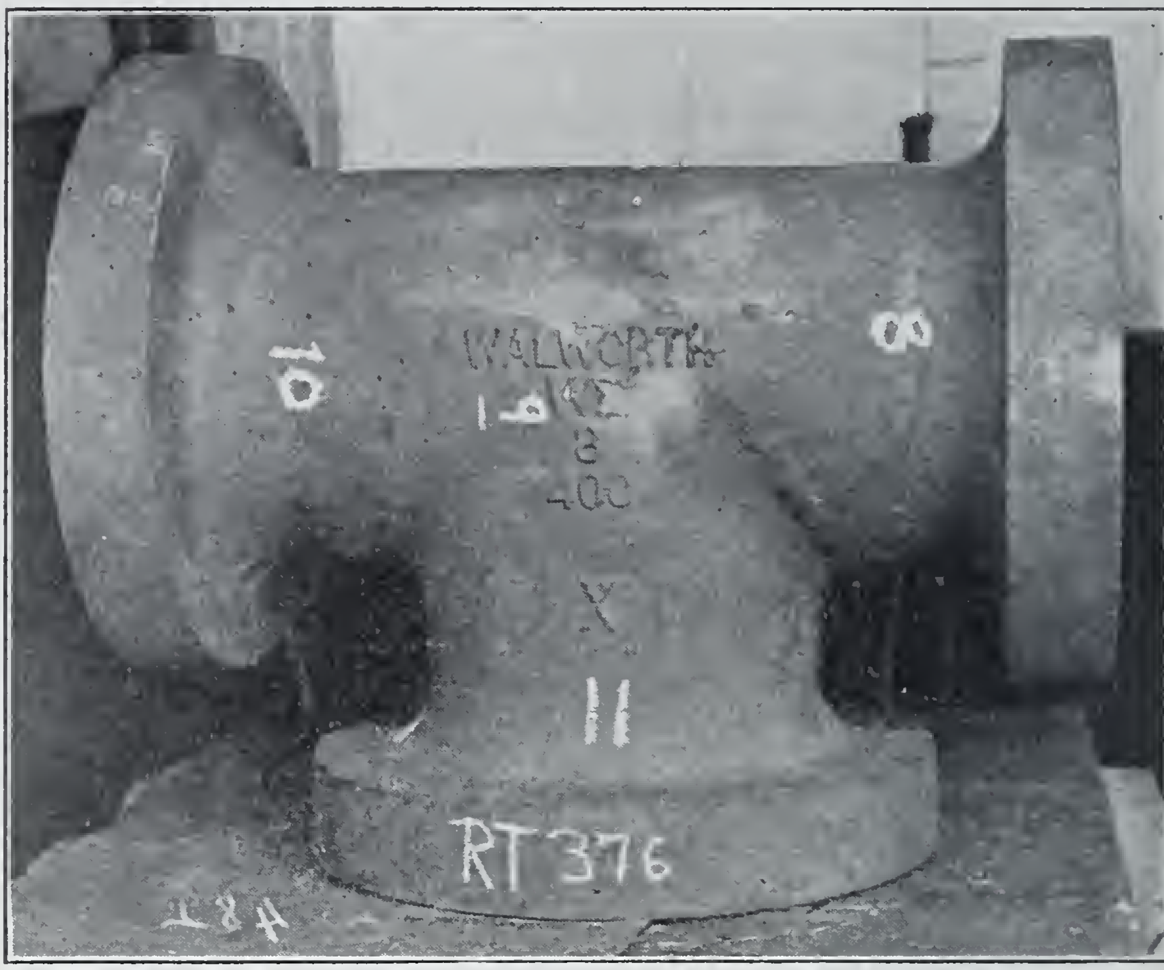

Fig. 14. Fitting Prepared for X-Ray.

Fittings are prepared for X-ray by assigning numbers to the areas to be surveyed. Lead wires are used to locate accurately the critical points, such as fillets and changes of sections. The study is necessarily made from the films themselves by holding them in front of a strong light. Reproductions of the films by any method are difficult to make and not satisfactory. I have attempted to show a few typical examples only.

Fig. 15 is representative of the effect of sand washing into the mold and becoming entrapped. It should be of interest to note that this exposure was taken on the lower or drag side of the casting. The gates failed with this result.

Fig. 15. X-Ray Showing Sand Inclusions.

Fig. 16. X-Ray Film of Sound Steel.

Fig. 16 shows an X-ray exposure of a section of sound steel free from defects other than small surface irregularities.

The interpretation of these films is an art in itself. The staff of the X-ray laboratory at Watertown Arsenal has become proficient in this work by making many comparative studies of the X-ray film exposures with both unetched and etched cross-sections cut from castings through the defects shown. Having an accurate interpretation of the films, it is possible to determine definitely the causes of the defects.

H. H. Lester, who is in charge of this laboratory, presented a paper before the American Society for Steel Treating, in September, 1924.* His paper very clearly described the various defects which occur.

In summarizing, Dr. Lester points the way to the elimination of defects which have been commonly accredited to steel castings:

"In this paper, casting defects as revealed by X-rays and collateral tests have been discussed. The defects as observed in castings may be summarized as follows:

1. Gas and sand pockets due to loose dirt in mold
2. Gas pockets due to imperfectly deoxidized metal
3. Sand inclusions due to cutting of mold or runners
4. Pipes caused by failure of risers to function as intended
5. Secondary pipes caused by flow of viscuous [sic] metal through constricted channels in the casting during the final stages of solidification
6. Cracks
7. Bad welds.

Of these defects the first three are easily preventable, the fourth may be prevented, but the prevention may necessitate a modification of design. The fifth may not be overcome entirely, but may be reduced to a minimum. The sixth may be prevented, but here, too, a redesign of the casting may be necessary. The seventh will not come up when the other defects are cared for."

HIGH-TEMPERATURE TESTS

An all-important consideration in the application of materials to high-temperature service is one of strength at the working temperatures.

Fig. 17 shows a typical curve drawn from tests at elevated temperature. The material tested was plain-carbon cast-steel (0.31 per cent. carbon) in its annealed state. It is interesting to note that the ultimate strength of this steel is about the same at 750 degrees F. as at normal temperature, although it falls off rather steeply at higher

*Trans. A.S.S.T., v. 6, p. 575.

temperatures. The yield-point had fallen only from 37,500 pounds per square inch at room temperature to 35,000 pounds per square inch at 750 degrees F.

This series of temperature tests was made in a horizontal testing-machine hydraulically operated. This machine is shown in Fig. 18.

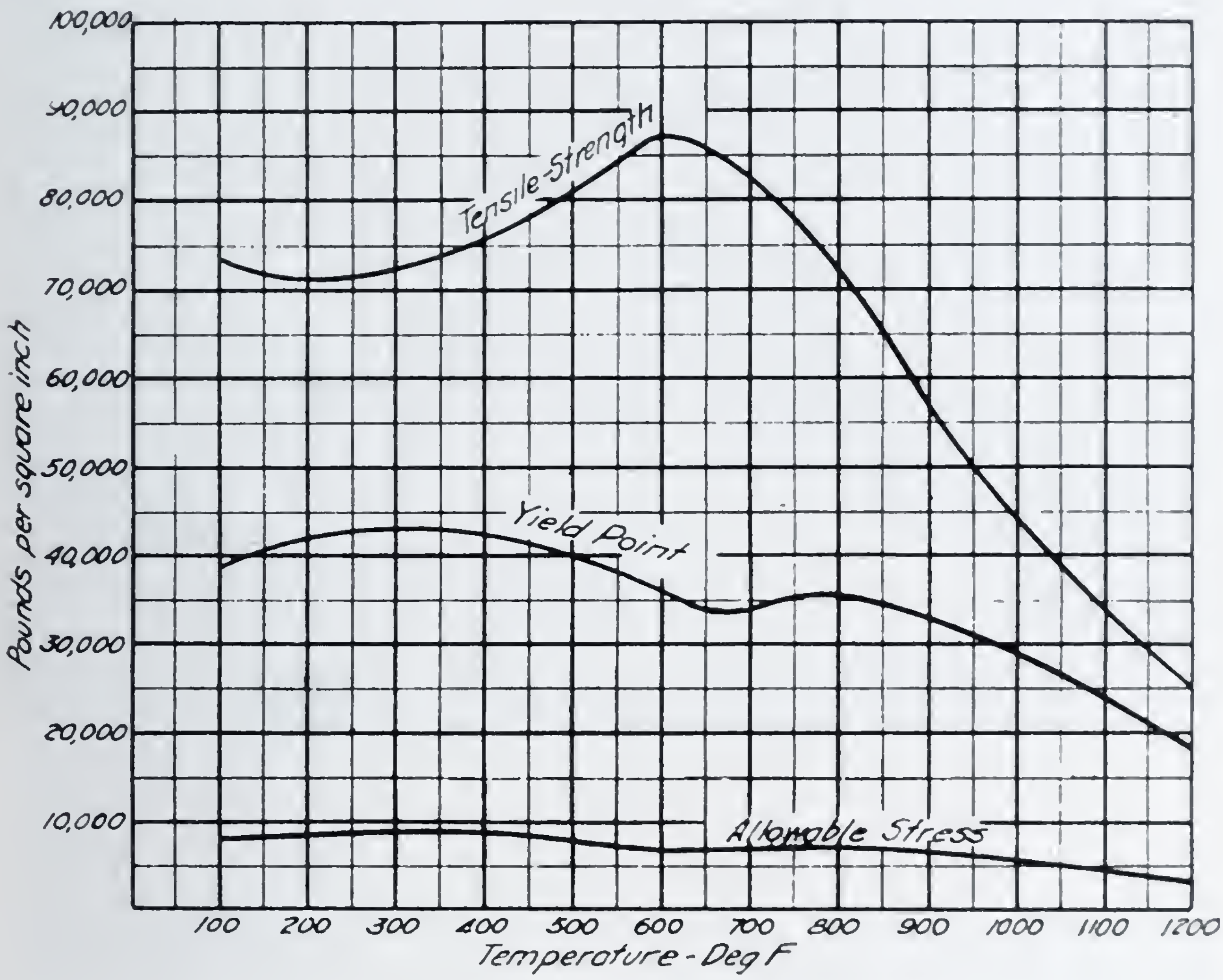

Fig. 17. Temperature-Strength Curve.

This type of machine is particularly well adapted to the work in hand because of the great amount of room available and because it holds the coupon and furnace in a horizontal plane.

The furnace used was about 16 inches long (Fig. 19), with a two-inch quartz flue wound uniformly with resistance wire. Because of the thickness of the furnace walls and the horizontal position of the furnace, interrupted windings were found to be unnecessary. The thermo-couple was in contact with the mid-portion of the gage length. The shape of the holders used is clearly shown in Fig. 20. The enlargements were entirely within the furnace. Their great heat capacity flattened the temperature gradient from the inside of the

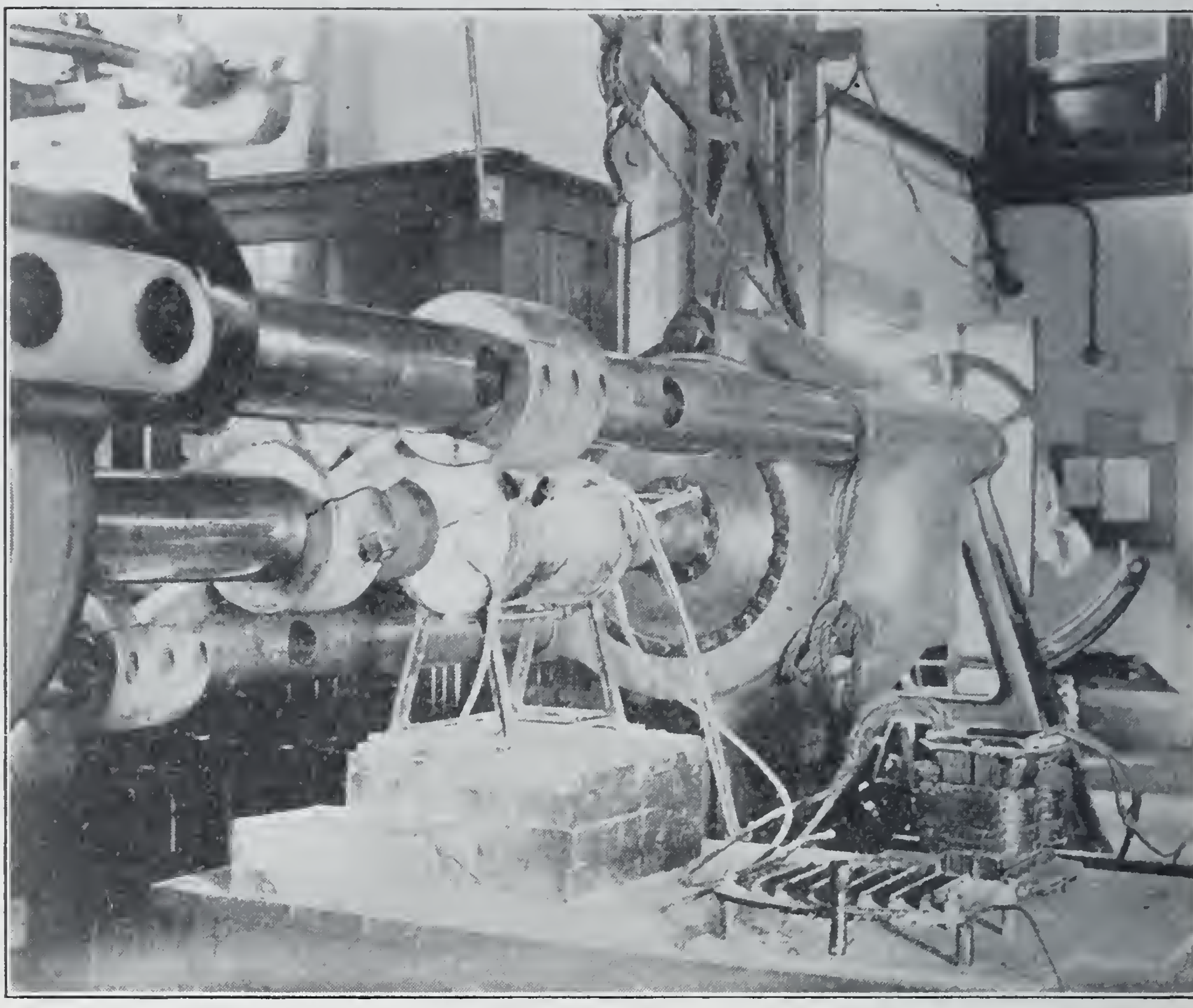

Fig. 18. Hydraulic Testing-Machine at Watertown Arsenal.

furnace because of the relatively small cross-section of that portion of the holder carrying the heat outward. It was possible at any time to place the hand comfortably on the nose of the machine. The yield-point was determined by the drop of the beam. Temperature was recorded by a Leeds & Northrup pyrometer. Temperature control was by hand with a vernier rheostat. Test-pieces were brought to temperature, requiring usually about three hours. After reaching the test temperature the furnace temperature was held constant for a period of at least one hour in order to determine from the pyrometer record that a balance had been reached.

These temperature tests formed the basis for an extensive investigation into the possibilities of applying pressure ratings at temperatures in excess of 750 degrees F.

Take as a basis the curves showing temperature and yield-point. Assume that the American Standard for steel flanges and flanged fit-

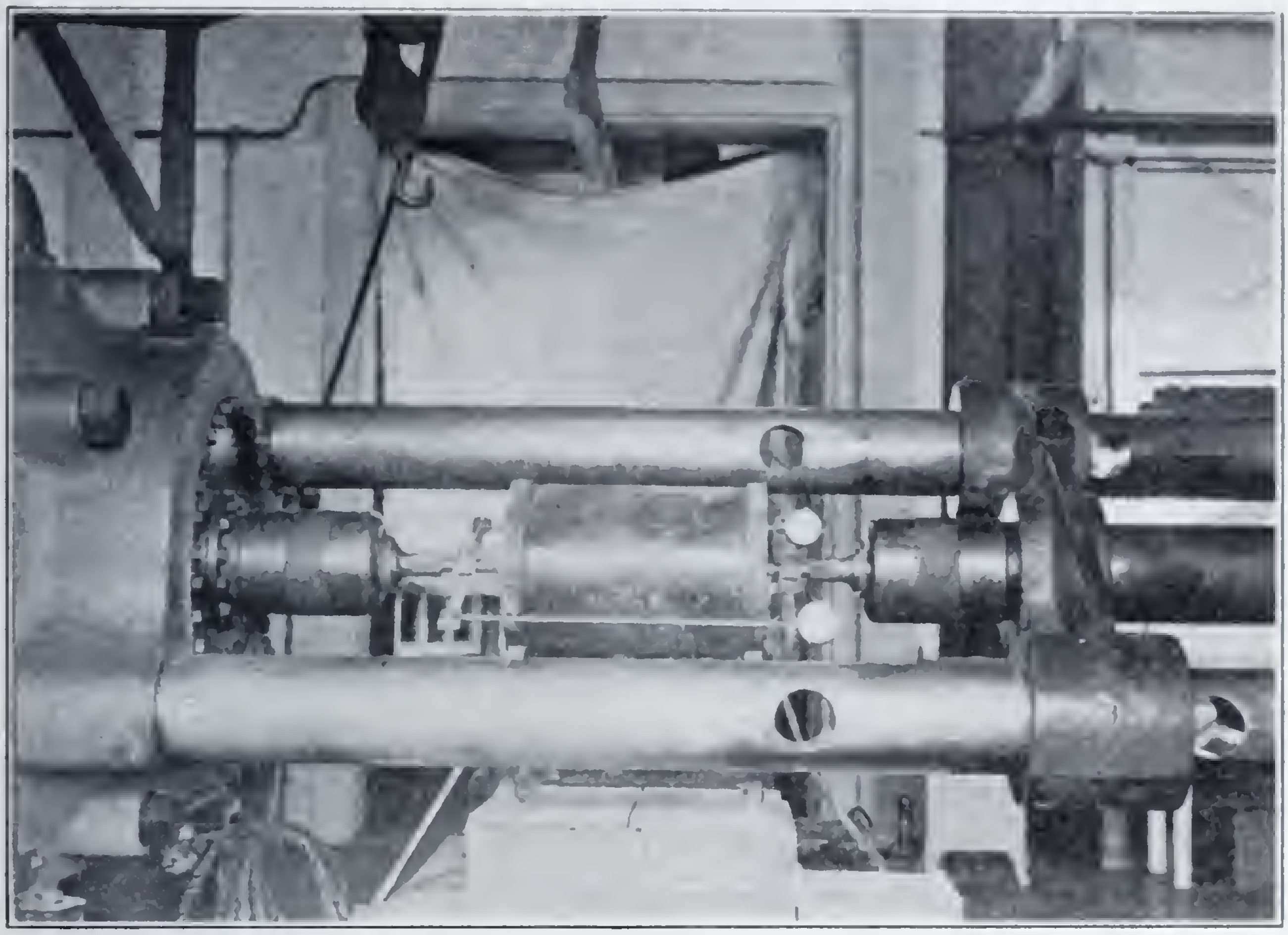

Fig. 19. Furnace for High-Temperature Tests.

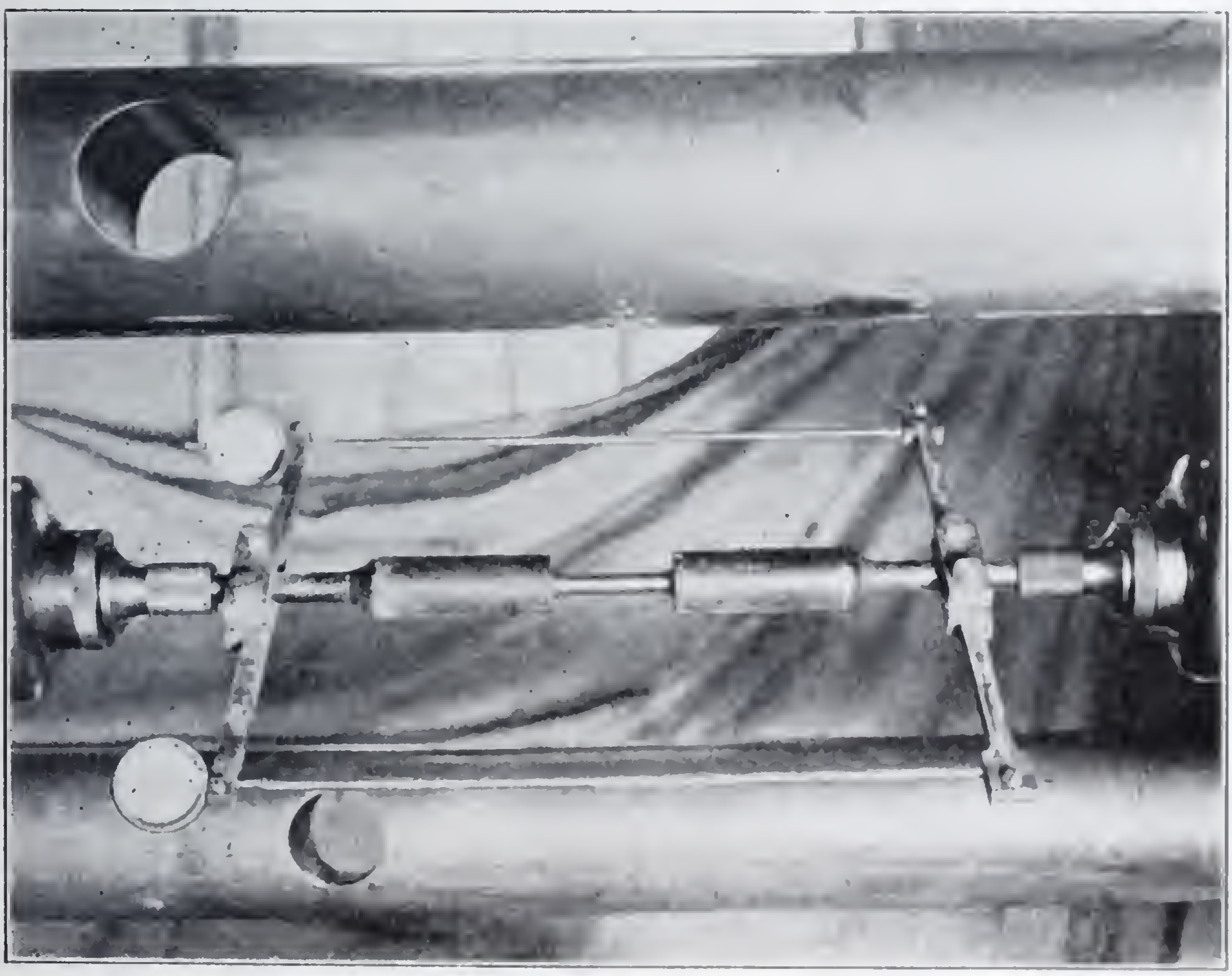

Fig. 20. Holders for High-Temperature Tests.

tings and the American Society for Testing Materials specification A 95-26 T are safe. We may plot a curve of allowable stress equal to one-fifth the yield-point at all temperatures (Fig. 17). Assuming the stress in a cylindrical section to be proportionate to this internal pressure we may immediately plot working-pressure and temperature curves. See Fig. 21.

Three points on these curves are fixed by the American Standard at temperatures of 100 degrees F., 450 degrees F., and 750 degrees F. The extension of the curves to 1200 degrees F. follows the shape of the allowable stress curves in Fig. 17.

There has been much discussion recently regarding the relative merits of plain carbon steels and alloy steels. This discussion is often more or less misleading because of the fact that both terms are indefinite. Plain carbon steel has a wide range of physical properties governed by its chemical composition and by its physical structure and freedom from hidden defects. The term alloy steel, when the chemical composition is not stated, is even more indefinite because it covers a great variety of alloys having an extremely wide range of physical properties which are materially changed by different methods of heat treatment.

High strength obtained by heat treatment with a relatively low drawing temperature may be largely lost by the action of heat during service. In castings of irregular cross-section such as the relatively thin walls and thick flanges of high-pressure valves and fittings, drastic heat treatment necessarily sets up high internal stresses in the casting, and these can not be relieved without reverting to a physical structure of lower strength.

The alloy steels available in valves and fittings contain very small percentages of the alloying elements, and if the additional strength imparted by the alloying elements is to be of value it must be uniformly distributed throughout the castings, the castings must be free from hidden defects, and the state of heat treatment must be such that the internal stresses in the castings are relieved. There is considerable evidence that this is not as readily accomplished in alloy-steel castings of this type as in plain carbon steel castings, where the chemical composition of the steel is less complex.

In comparing the physical properties of plain carbon steels and alloy steels, the chemical composition and state of heat treatment of

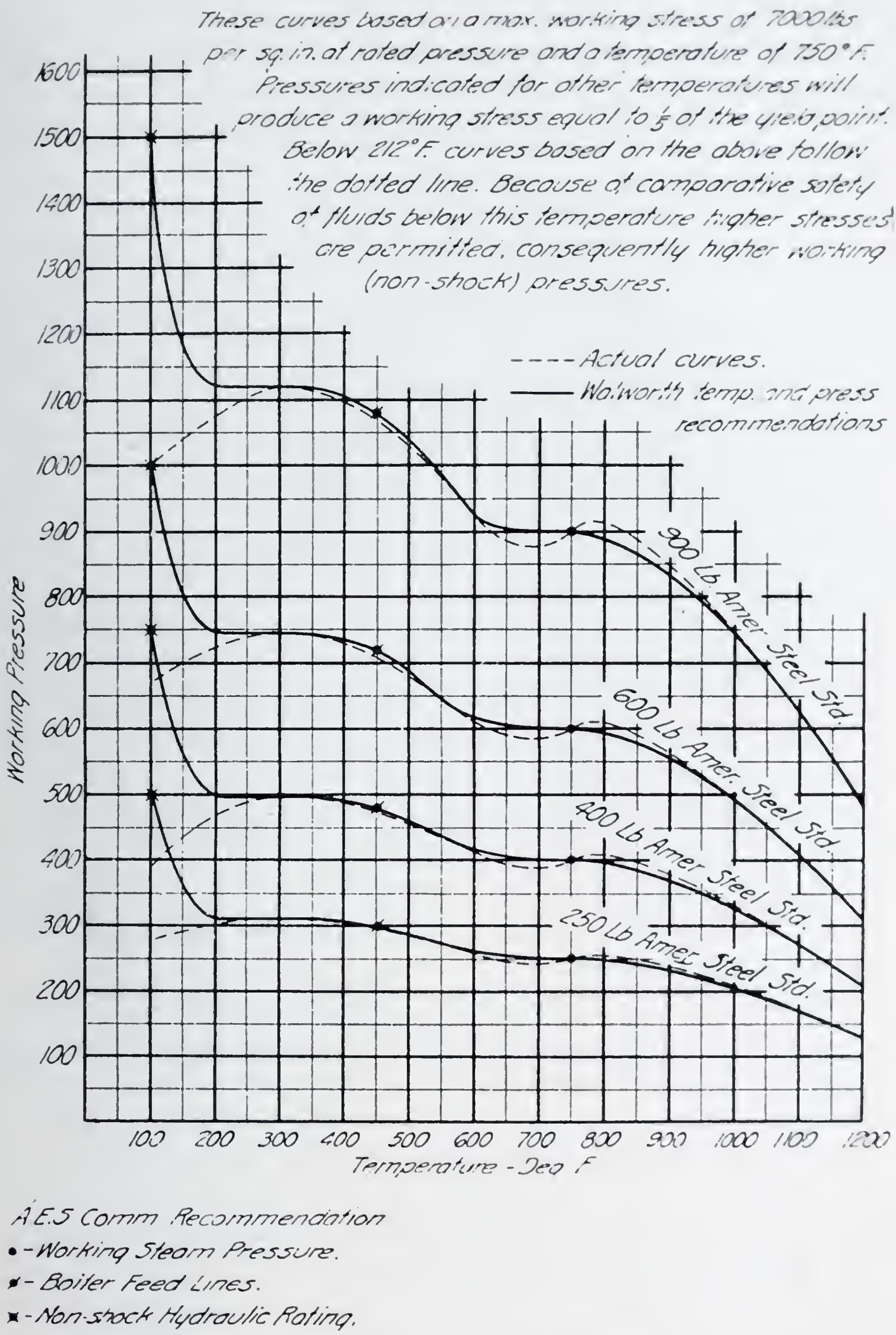

Fig. 21. Pressure-Temperature Curves.

each metal should be definitely known, and it should be borne in mind that the test-bar strength does not necessarily represent the strength of the metal at the vital parts of the casting unless it be known:

1. That the alloying elements are uniformly distributed through the casting.

2. That the casting is free from hidden internal defects.

3. That the internal stresses in the castings are thoroughly relieved.

Plain carbon steel valves and fittings can be designed to provide an ample factor of safety, and the uniformity of the metal in the casting can be controlled within safe limits.

Much is being written at this time on the subject of testing materials under long-sustained load at high temperatures. If we are to believe some writers on the subject, ordinary steel is unstable at stresses as low as 400 pounds per square inch continuously applied at temperatures not greater than are in use in piping installations.

The conclusions drawn and inferred from published statements of this kind are in some cases directly contradictory to actual service records of the material in question. While the creep in metals when simultaneously subjected to elevated temperatures and high stresses is a matter requiring careful consideration when untried service conditions are imposed, there is no occasion for undue alarm when laboratory tests appear to indicate a condition not shown by actual service tests of long duration. Some of the testing equipments used are of improper design, and in some cases the results obtained have been erroneously interpreted.

The most usual error in the design of long-time testing equipment is the total neglect of the effects of friction in the mechanism employed, and the variations in temperature in the furnace and in the room.

The friction of the mechanism is deducted from the effect when the specimen attempts to raise the weights. In some cases the frame of the testing-machine is of considerable length, so that small changes in room temperature produce relatively large effects on the specimen under test. Some writers neglect consideration of the scaling effect of the high temperature. While each of these individual errors may be small, they all tend to lower the indicated stress, and are therefore cumulative.

It seems logical to assume that the best appliance for tests of this sort is a direct load and that accurate comparative results may be had only from standard-size tension-test specimens of 0.505-inch diameter, with two-inch gage length.

DESIGN OF FITTINGS

Pipe fittings permit the junction of pipes and the possibility of change in direction. Two types are commercially available—screwed fittings and flanged fittings. The former are generally internally threaded, making the joint directly to the external thread on the pipe. The latter are provided with flanges for connection by bolting.

Screwed fittings have not been favored by designing engineers for high-pressure steam service, although they have been eminently satisfactory in hydraulic installations operating at pressures many times that of the highest steam pressures. The reasons for this lack of favor are probably all traceable to the temperatures rather than to the pressure. Screwed connections, properly cut, and intelligently applied and made up, form the least troublesome and most reliable type of pipe connections.

Because a portion of the pipe wall is cut away and because a few threads or scratches are exposed outside the face of the fitting, screw-threads should not be used when the piping is subjected to vibration, nor when severe side strains are encountered. Here again we place a temperature limitation on their use.

Flanged steel fittings undoubtedly have the call for high-pressure steam. The recently published (June 1927) Tentative American Standard for steel flanges and flanged fittings (American Society of Mechanical Engineers, B 16e—1927) defined the principal dimensions for flanged steel fittings for steam pressures of 250, 400, 600, 900, and 1350 pounds per square inch. These ratings apply at maximum temperatures of 750 degrees F. The publication of this standard is the culmination of more than five years' work by a sectional committee organized under the procedure of the American Engineering Standards Committee.

A committee of the American Society for Testing Materials, working at the same time, developed specifications (A 95-26 T) for carbon-steel castings for high-temperature service. These two stand-

ards are presumed to cover the steel flanged fittings themselves, both as to material and dimensions.

It might be interesting to point out a few of the peculiarities of each of these standards.

The American Standard 250-pound flanges are of practically the same dimensions as the 1914 extra-heavy cast-iron flanges. This standard for cast-iron flanges had been in partial use previous to 1918. At that time it came into general use and, on the whole, proved entirely satisfactory at 250 pounds steam pressure. Two small sizes (2-inch and 2½-inch) may have been inadequately bolted.

When the steel flange standard for 250 pounds was made dimensionally equal to the extra-heavy cast-iron standard, the steel standard was at once discredited. It seemed wasteful that flanges of steel having a safe allowable working stress of 7000 pounds per square inch should be rated no higher than the same flanges in cast-iron where the safe working stress hardly exceeds 2200 pounds per square inch. Manufacturers and consumers united in a rating of 300 pounds on the steel flanges.

Another point in the American Standard which renders it vulnerable is the use of Barlow's modified formula in the calculation of wall thicknesses. Birnie's formula is more nearly theoretically correct, and is especially so in calculations dealing with cylinders having walls relatively thick. It is to be hoped that in the development of standards for 2000 and 3000 pounds the more accurate formula will be used.

Fig. 22 shows a simplified plan for the application of Birnie's formula.

Still another assumption in the American Standard is that the weakest regular fitting (a tee) is two-thirds as strong as a cylinder having the same port diameter and wall thickness. Birnie's formula shows a bursting strength of 3212 pounds per square inch on a 12-inch cast-iron cylinder one inch thick, at a fiber stress of 22,000 pounds per square inch. Barlow's modified formula shows 2828 pounds for the same cylinder.

If we assume a 12-inch, extra-heavy, cast-iron tee to be two-thirds as strong, we would expect a bursting pressure of from 1885 to 2140 pounds per square inch. Actual tests indicate a bursting pressure of about 1400 pounds per square inch. This would seem to indicate

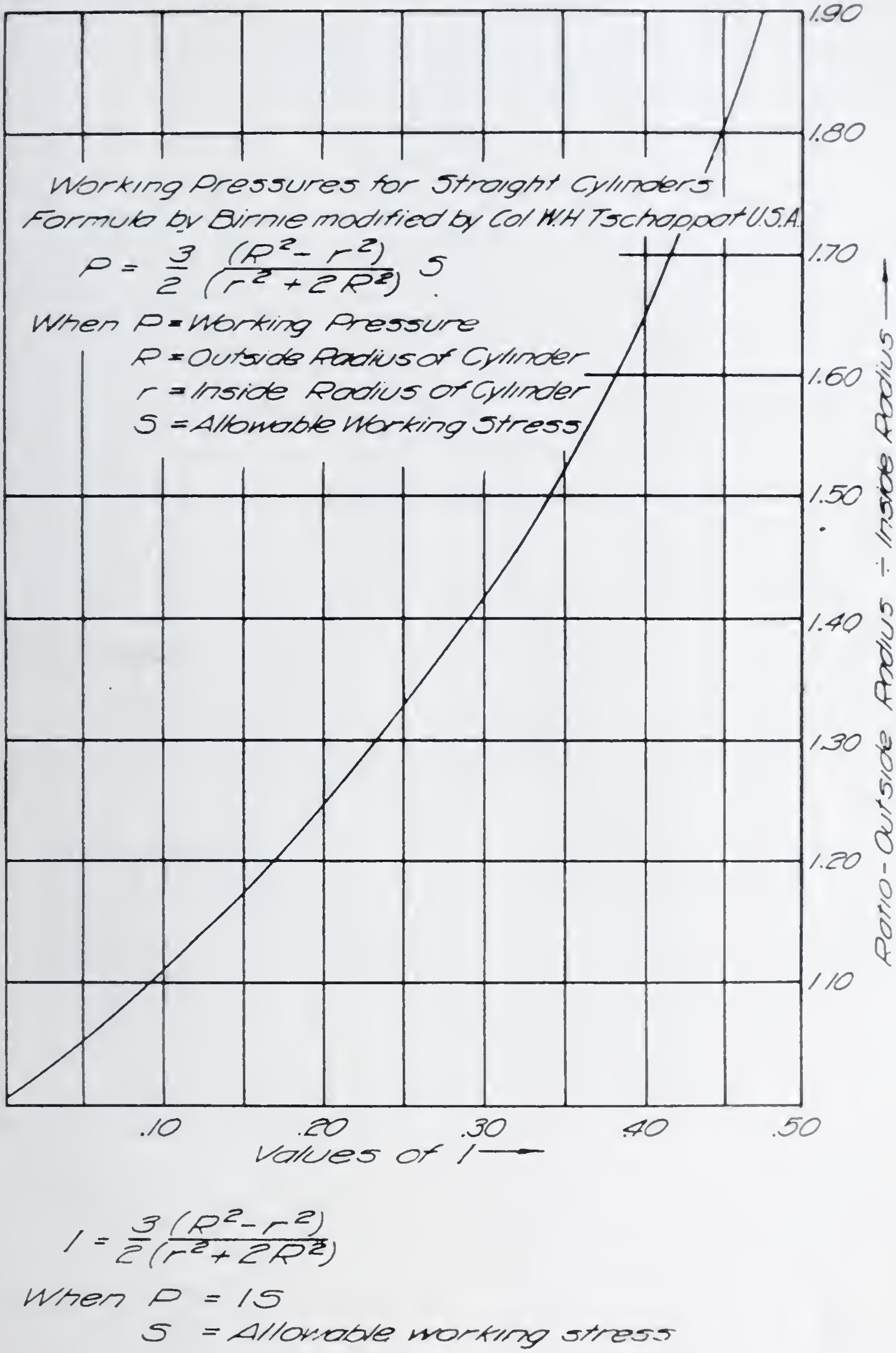

Fig. 22. Birnie's Formula.

an efficiency of shape from 44 to 50 per cent. rather than 66 per cent. as assumed in the standard.

Forty-five degree Y's are even weaker than tees, but these are presumed to be reinforced by ribs, or otherwise, to compensate for the inherently weak shape.

VALVES

The early history of valves has been previously mentioned in this paper. The progress during the past 10 years is the most spectacular development of all time along these lines. Like a long-dormant volcano bursting forth in violent eruption, primary steam working pressures have soared from an upper limit of about 200 or 250 pounds per square inch, which appeared to be as permanently fixed as the Rock of Gibraltar, to higher and higher levels ranging from 350 to 1350 pounds per square inch, and several power-plants of commercial size, to use still higher working pressures of steam, are being developed.

During the same period, working temperatures of steam have risen in this country from 600 to 750 degrees F., with some European plants approaching a working temperature of 900 degrees F. That the recently issued Tentative American Standard B 16e—1927 for steel pipe flanges and flanged fittings has been compiled for maximum steam working pressures of 250, 400, 600, 900, and 1350 pounds per square inch at a temperature of 750 degrees F. is mute evidence of the importance of this matter. This sudden demand for valves to control previously unheard-of steam pressures and temperatures has established new requirements in design, materials, and workmanship. I shall now endeavor to outline some of the features of a line of modern, high-pressure, high-temperature gate-valves which have been designed and manufactured to meet the needs of these new service conditions. These valves are available in the ordinary range of sizes for each of the working pressures specified in Tentative American Standard B 16e—1927.

Fig. 23 is an exterior view of one of these valves. This gives a good idea of the general appearance of the entire line.

Fig. 24 is a typical sectional view showing the general construction which was used consistently throughout the line, with minor variations as required because of size limitations and working-pressure requirements.

In discussing valves for high-pressure, high-temperature steam service, much attention has been given to design and materials, and

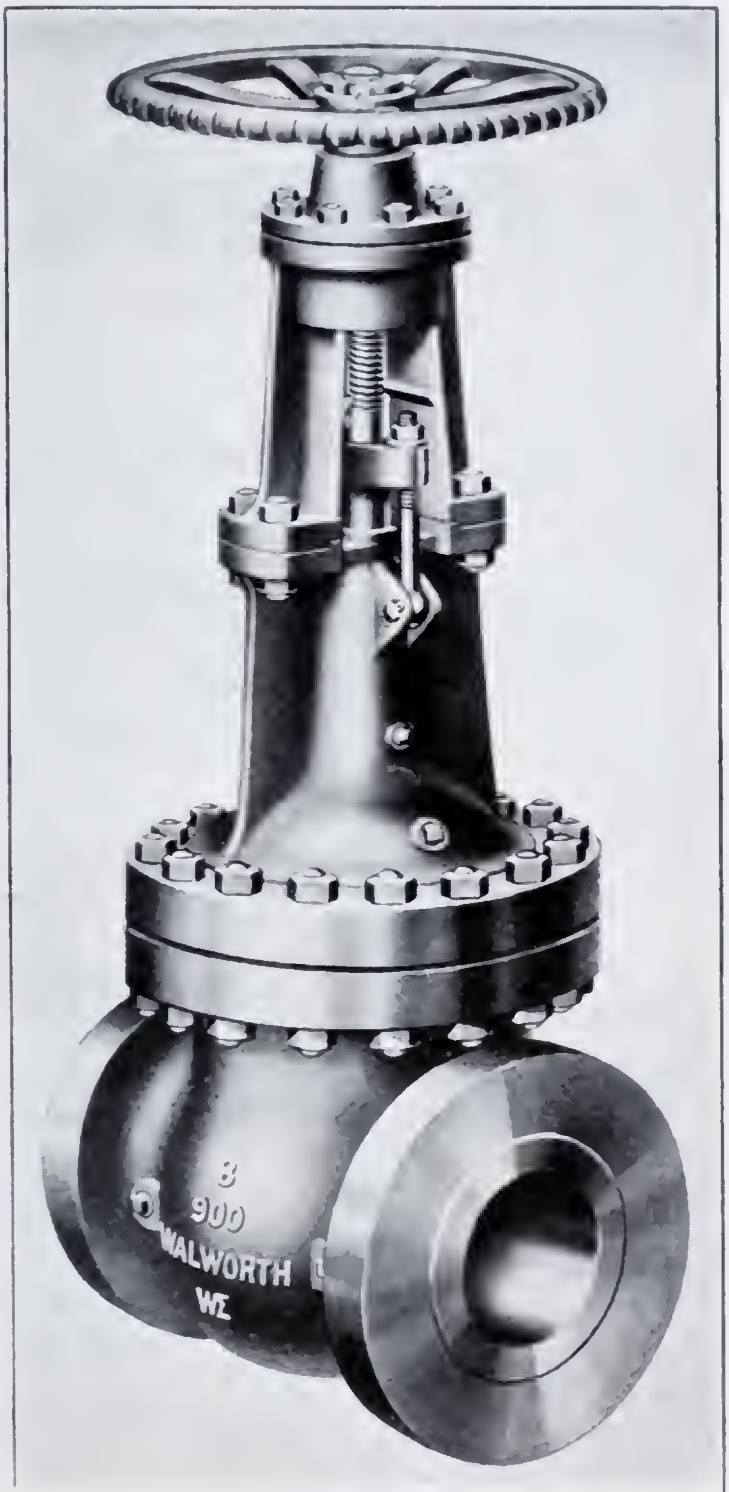

Fig. 23. American Standard Steel Gate-Valve.

rightly so. However, in order to assure a properly functioning mechanism in every instance, the question of workmanship, continuous control of manufacturing operations, and testing of product are obviously matters of equal importance.

The control of fits in the manufacture of interchangeable parts has been receiving a great deal of attention during the past few years. It is evident that a definite permissible shop tolerance in the dimensions of mating parts must be established and carefully controlled if proper fits are to be uniformly secured. Methods of control have

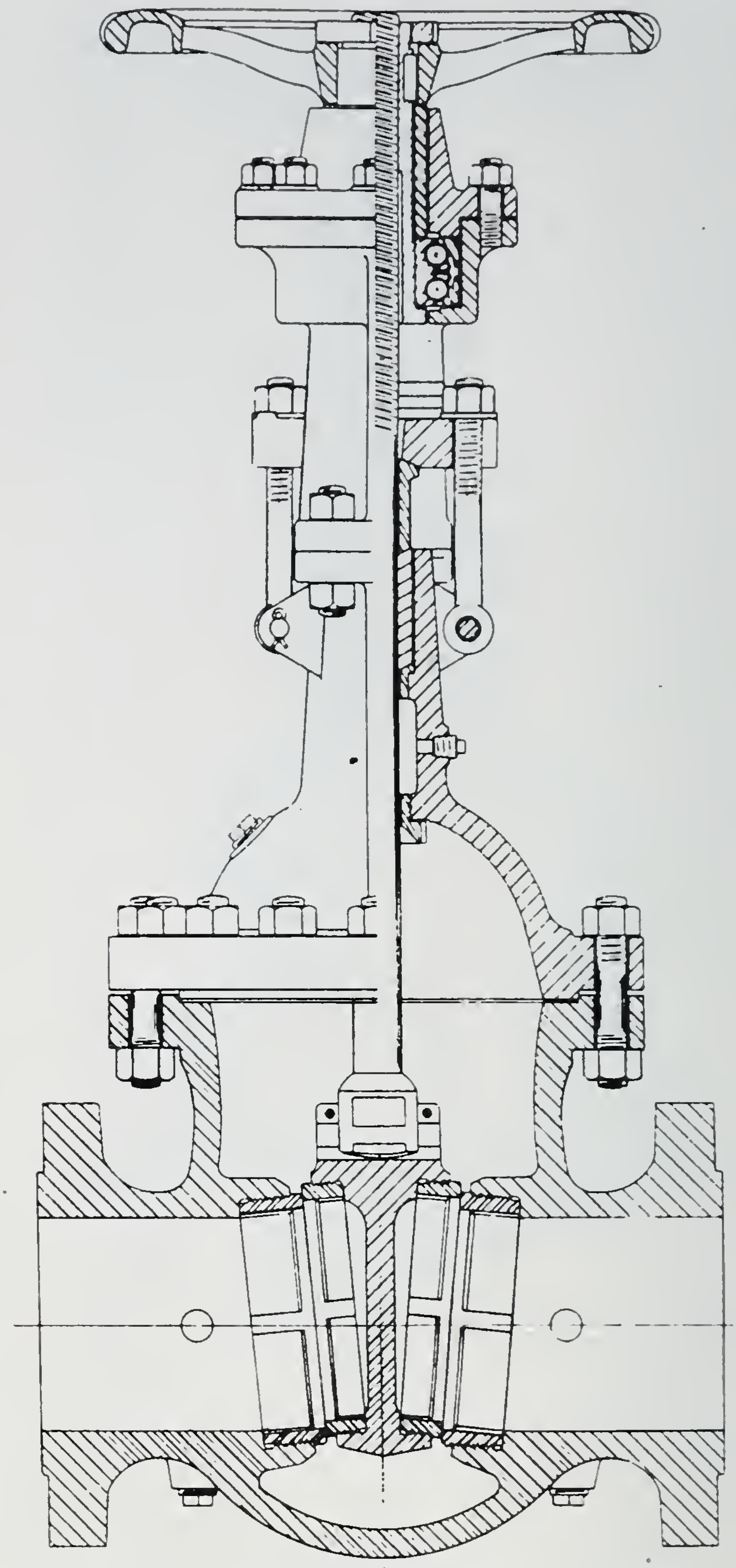

Fig. 24. Section of American Standard Steel Gate-Valve.

varied widely in different industries and in different plants in the same industry. The formulation of standard methods, which is now well under way, will be a great help in eliminating the chaotic conditions which have existed, and in developing standard uniform methods for controlling fits so that the desired functions will be performed.

This matter is well covered by Tentative American Standard B 4a—1925, for tolerances, allowances and gages for metal fits. In this line of valves, ample bearing surfaces are provided with small allowances, or clearances, between mating parts so that proper functioning of the parts is assured even after long service has resulted in considerable wear of the contact surfaces.

The use of limit gages controls the maximum and minimum sizes of mating parts and insures the maintenance of the allowances (clearances) within the prescribed limits. Careful inspections are made after each machining operation, both as to accuracy of dimensions and quality of finish. Ample facilities are provided so that the testing of large orders may be carried out expeditiously without delaying the customer's inspector. All finished product is carefully inspected after it is prepared for shipment, to assure its arriving at its destination in good condition.

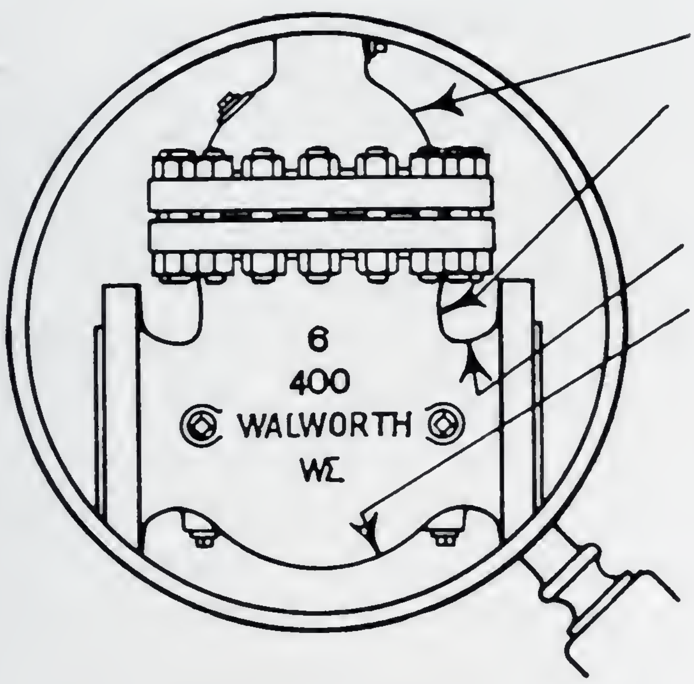

Fig. 25. Gate-Valve Body and Bonnet.

Fig. 25 is a view of the pressure-containing portion of the valve body and bonnet showing the use of cylindrical and spherical surfaces which are much more suitable than flat or oval surfaces for confining internal pressures without serious distortion. The patterns for these castings were specially designed and developed for casting in steel, using easy curves to join the changes in contour of the casting, and as far as possible giving a uniform distribution of metal. Where the junction of relatively thick and thin sections, such as the flange and the body wall, could not be avoided, large fillets of special design were

developed to eliminate the danger of forming cracks and shrinkage cavities. The wall thicknesses were established by adding a suitable increment to the thicknesses specified in Tentative American Standard B 16e—1927 in order to cover foundry variations, the increment of course being added to the outside of the casting so as to maintain the specified inside diameter. The flange dimensions conform to the American Standard and the depth of spot facing is carefully controlled so as to insure the full specified flange thickness and at the same time permit the use of bolts of standard length.

The seat rings are supported in circular hubs projecting inward from the body wall, away from the exterior heat radiating surfaces. This construction gives uniform temperature of rings and supporting metal so that they will expand and contract alike under variations in temperature, if the coefficients of expansion are reasonably close together. It also eliminates warping of the seating surfaces by unequal temperatures at different parts of the ring.

The joints between the body and the seat ring are made on the entering end of the seat ring, instead of under a projecting flange at the trailing end of the seat ring as is done in the conventional flange type. This puts the seat ring in compression instead of in tension and bending so that less deformation is possible, and the ring is consequently better able to withstand, without distortion, stresses caused by expansion and contraction. When the joint is made on the end of the ring inside of the thread connection it can also be made up tighter than is possible under a flange outside of the thread connection, due to the fact that the moment arm of the frictional resistance to rotation at the joint surface is considerably less. This construction also provides a straight cylindrical bore through the valve and eliminates the customary recess in the body at the entering end of the conventional flange-type seat ring as well as the shoulder formed by the end of the ring. This permits the least possible disturbance to straight-line flow through the valve, and eliminates pockets and obstructions that tend to accumulate sediment and adhering deposits.

Fig. 26 shows the method of attaching the disk rings to the disk, which is the same as that used for securing the body seat rings. This construction assures tight joints between the rings and the disk, and the rings may be readily replaced if they become injured or so worn in service that they can not be reseated.

Fig. 26 also shows the rugged construction of the guides for the valve disk. Both the guides and the disk slots are accurately machined to close tolerances and have small clearances. The guides on opposite sides of the valve are of unequal thickness so that the disk can be

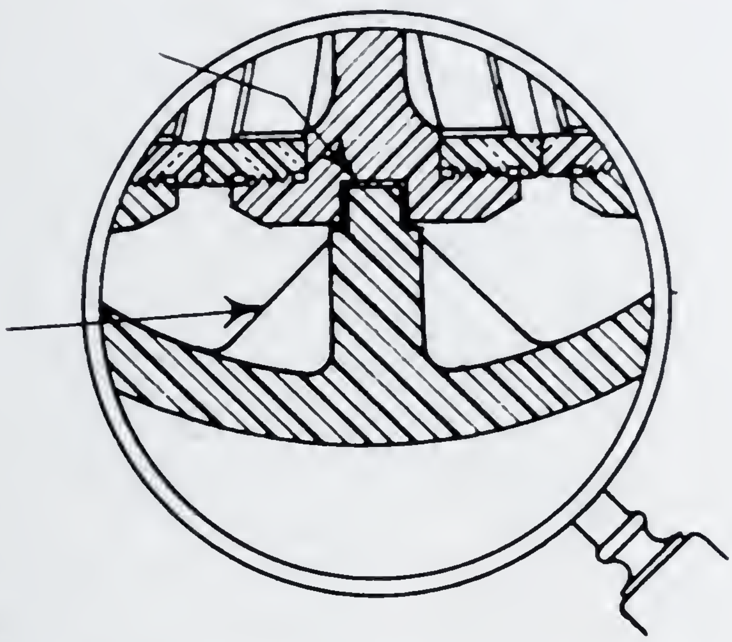

Fig. 26. Gate-Valve Disk Rings and Guides.

mounted in the body in only one position. Ample bearing surfaces on the guides are provided, the maximum bearing pressure used being approximately 8000 pounds per square inch. The bearing surface of each guide on the 12-inch, 400-pound valve, for instance, is five-eighths of an inch wide and 7¼ inches long.

The method of connecting the stem to the disk forms a substantial construction and at the same time freely permits self centering of the disk in the body seats, thus preventing the setting up of bending stresses in the stem. The connection on the end of the stem, and the disk slot in which it engages, are both accurately machined to close tolerances. The stem is of one-piece construction, being machined from a solid rolled or forged bar, and the stem threads are "Acme" standard.

In designing these valves, the entire line, including all sizes and pressures, was considered as a whole, and the dimensions of various parts properly scaled up for increasing sizes and pressures. Wherever possible, parts were also made interchangeable so that the same parts may be used in two or three or more different valves. For instance, a definite size of hand-wheel is always used with a certain

size of stem, and all parts engaging with the stem—such as the wheel nut, keys, yoke nut, gland plate, gland, stuffing-box bushing, and bonnet bushing—are standard for that size of stem. This permits larger production runs, and simplifies the stocking of replacement parts. The stem diameters were figured both for combined compression and torsional stresses and for combined shear and torsional stresses. On the 14-inch, 400-pound valve, for instance, the stem is two inches in diameter, the hand-wheel is 26 inches in diameter, the pitch and lead of the "Acme" standard stem threads are one-third of an inch, and the stem thrust is 18,200 pounds. This same stem, except for variations in length, is also used on the 12-inch, 600-pound; the 10-inch, 900-pound; and the eight-inch, 1350-pound valves.

The male-and-female bonnet joint is standard for the 400-pound and 600-pound pressure valves. On the 900-pound and 1350-pound pressure valves, the standard connection is of the tongue-and-groove type. Both of these constructions assure accurate alinement of the body and bonnet. The bonnet flanges are designed to provide ample strength and are machined all over. Unless otherwise specified, the bonnet gasket is "Garlock" 902 for the male-and-female joints, and aluminum for the tongue-and-groove joints. The bonnet studs have nuts on both ends and are made of alloy steel conforming to specification A 96-26 of the American Society for Testing Materials, Class "C" having a tensile strength above 125,000 pounds per square inch and a yield-point above 105,000 pounds per square inch. The bonnet-joint design is based on a maximum safe working stress in the studs of 9000 pounds per square inch, as specified in Tentative American Standard B 16e—1927. The total load on the bonnet studs is determined by assuming the internal working pressure to act upon an area circumscribed by the periphery of the outside of the contact surface of the joint, and adding to this the maximum thrust of the valve-stem.

Fig. 27 shows the large condensing or pressure relieving chamber that is provided just below the stuffing-box. At the lower end of the condensing chamber is a carefully machined seat between the stem and the bonnet bushing, which cuts off the line pressure from the stuffing-box and permits repacking under pressure when the valve is wide open. At the upper end of the stuffing-box chamber is shown the stuffing-box bushing which supports the packing in the stuffing-box. Both the bonnet and the stuffing-box bushings are made of the

same grade of trim material as is used for the valve-seats. In addition to their other functions, these bushings act as guides for the stem and may be replaced if they become injured or worn in service.

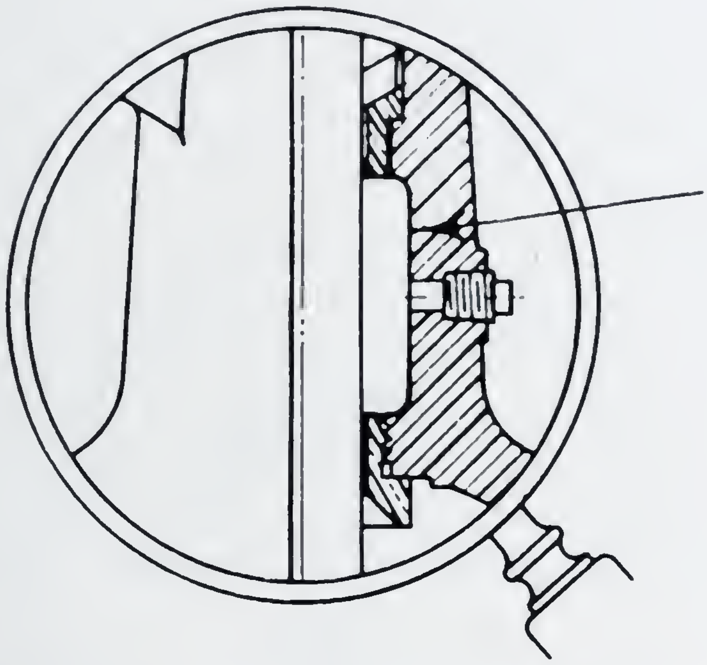

Fig. 27. Gate-Valve Condensing Chamber.

The deep stuffing-box construction used provides ample room for adequate packing and a long contact surface between the packing and the stem. The packing in the 12-inch, 400-pound valve, for instance, is one-half inch thick and four inches long; and in the 12-inch, 900-pound valve is one-half inch thick and six inches long. The packing used is varied according to the service. It is of the inverted-cone type, so that the steam pressure acting on the small end of the conical packing tends to flatten down the cone, thus increasing the effective width of the packing and securely sealing off all leakage.

The gland and self-adjusting gland-plate construction provide a ball-joint which prevents cramping of the gland on the stem when nuts are unequally tightened. The gland is made of high-grade trim material.

The ends of the gland plate are slotted, permitting the nuts to be slackened and bolts swung out for repacking without removing the nuts, thus eliminating the possibility of misplacement or loss of bolts and nuts. Retaining lugs one-eighth inch high are provided at the outer end of gland-plate slots which securely hold the washers under the gland-bolt nuts in their proper position, and the bolts can not be swung out until the nuts are backed off more than one-eighth inch

and the washers lifted so that they will clear the tops of the retaining lugs. The gland bolts are made of forged alloy steel conforming to specification A 96-26 of the American Society for Testing Materials, covering bolting material for high temperature service.

A male-and-female joint is also used in the connection between the yoke and the bonnet, thus accurately centering these parts and insuring proper alinement of the valve-stem.

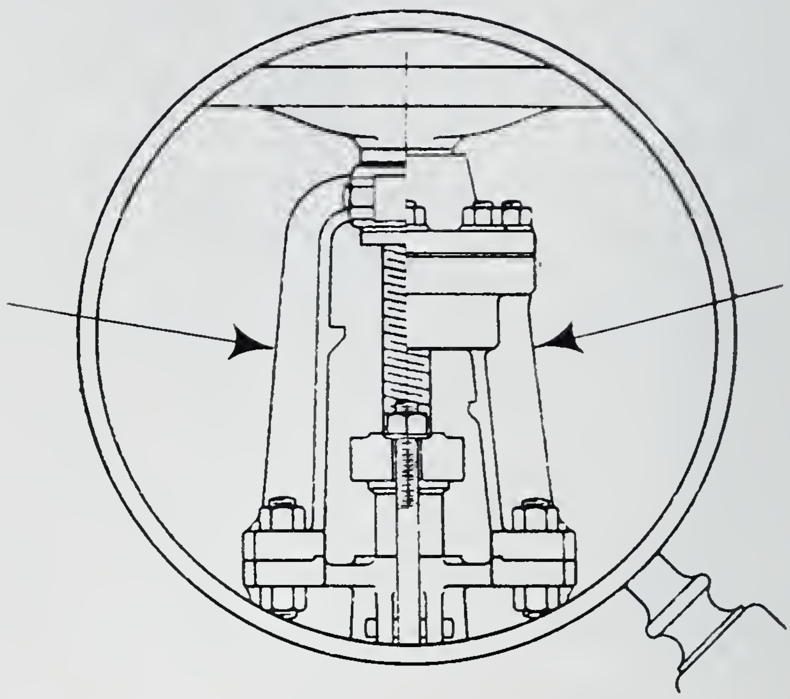

Fig. 28. Comparison of Gate-Valve Yokes.

Fig. 28 shows how, in the larger sizes of valves, the ball-bearing yoke is made interchangeable with the plain yoke using standard stem and hand-wheel. This standardization feature is of value from the standpoint of manufacture and also makes it possible to change the type of yoke on the valve in the field with a minimum of labor and parts for replacement.

In applying motor operation, standardization is again brought into play and a field change may be readily made if desired. The motor bracket is cast solid on the ball-bearing yoke cap, and the motor and driving gears are added, using the standard ball-bearing yoke construction with standard ball-bearing yoke nut and standard stem and hand-wheel. The motor bracket may be set at any angle so as to locate the motor in the most convenient position.

The hand-wheel is of rugged design. It is made of cast-steel, thus insuring against the annoyance and sometimes serious incon-

venience caused by breakage either during shipment or in service. It has corrugations on the outer diameter to facilitate gripping and is specially designed to fit the hand.

The body seat rings, disk rings, stem, bonnet bushing, stuffing-box bushing, gland, and yoke nut are included under the classification of trim material. A feature of this line of valves is that the design permits the use of practically any material—cast, forged, soft annealed, or heat treated—that may be found particularly suited to meet the service requirements of each individual part. The trim materials of the valve are located at the vital points of attack, and being subject to the ravages of heat, corrosion, erosion, abrasion and wear, it is obviously highly desirable to be able to apply the best available materials for the particular service and to renew the parts readily when necessary. The new conditions of steam temperature and pressure which have sprung into existence during the past few years have been the inspiration for a great deal of experimental and field investigation of various materials for valve trim, particularly for valve-seats and valve-stems. Numerous nickel-copper alloys and stainless steels of widely differing compositions have been tried. "Monel" metal under superheated steam temperatures of around 600 degrees F. and at pressures up to 300 pounds or higher has been extensively used for a number of years and has proved quite satisfactory as a trim material. At the same time, while many users report satisfactory service at the higher temperatures and pressures now in use, there have been some instances reported of seat rings loosening in service and also of seizing and spalling of the seating surfaces. The experience with "Monel" metal on high-temperature steam service of the company with which the writer is associated has been uniformly satisfactory. The cost of good castings from "Monel" metal when not adulterated with tin, lead, or other metals, however, is very high, and consequently forged "Monel" has largely replaced cast "Monel" for valve trim when the design is such that this can be done economically. Having in mind, however, that in certain quarters "Monel" metal appeared to be open to question, and having in mind also the fact that the metal with which trouble was reported may or may not have been true "Monel," and that the design may or may not have been sound, the company with which the writer is associated undertook about two years ago a rather extensive series of tests and investigations of stainless steel. An

important part of these investigations, which brought out some rather startling and unexpected results, was the determination of coefficients of expansion of plain carbon cast-steel and a number of different compositions of stainless steel, some containing chromium only and others containing both chromium and nickel. The general conclusions reached in this study were as follows:

1. Plain carbon steels were found to have nearly linear expansion curves up to 600 degrees C. (1112 F.).

2. The coefficient of thermal expansion for such steels was found to be unaffected within limits of practical usefulness by variations in carbon content and by variations in heat treatment.

3. The average coefficient for the 15 specimens tested was found to be 0.146×10^{-4} per degree C. (0.811×10^{-5} per degree F.). The variations from this value occurred in the third significant figure and covered a range from 0.143×10^{-4} per degree C. (0.794×10^{-5} per degree F.) to 0.147×10^{-4} per degree C. (0.817×10^{-5} per degree F.).

4. Steels containing chromium have expansion curves similar to those for carbon steels, except that the coefficient is smaller and the values found for the coefficients varied in an irregular manner.

5. In general, it was found that the greater the chromium content, up to about 26 per cent., the smaller the coefficient of expansion.

6. It was found that such steels, quenched from a high temperature, showed smaller coefficients than the same specimens when in an annealed state.

7. The values of the coefficients found for the above steels containing one per cent. or more of chromium ranged from 0.140×10^{-4} per degree C. (0.778×10^{-5} per degree F.) for steel with 1.75 per cent. chromium to 0.113×10^{-4} per degree C. (0.628×10^{-5} per degree F.) for steel containing 26.23 per cent. chromium.

8. Lower values than the above were obtained in some cases by special heat treatments. The variations found on heat treating single specimens ranged from 0.126×10^{-4} per degree C. (0.700×10^{-5} per degree F.) for a specimen quenched from 1065 degrees C. (1949 degrees F.) and drawn three hours at 740 degrees C. (1364 degrees F.) to 0.108×10^{-4} per degree C. (0.600×10^{-5} per degree F.) for the same specimen water quenched from 1000 degrees C. (1832 degrees F.).

9. Nickel-chromium steels also showed expansion curves similar to those found for plain carbon steels, except that, as with the chromium steels, the coefficients of expansion showed irregular variation.

10. In general, the presence of nickel was found to increase the value of the coefficient over what might have been expected if no nickel were present. The range of variation in the coefficients found with varying nickel content and with specimens in annealed states was from 0.114×10^{-4} per degree C. (0.633×10^{-5} per degree F.) for steel containing 3.55 per cent. nickel and 20.38 per cent. chromium to 0.187×10^{-4} per degree C. (1.040×10^{-5} per degree F.) for steel containing 20.40 per cent. nickel and 7.82 per cent. chromium.

11. The coefficients were found to vary with heat treatment of the specimens, as in the case of the chromium steels.

12. It was found that coefficients obtained after heat treatments were not constant, but varied with subsequent tests, even though heated in the test to a point below the temperature of the heat treatment. These variations were found to be of relatively large magnitude, as illustrated in one typical case where the coefficient changed from 0.151×10^{-4} per degree C. (0.840×10^{-5} per degree F.) to 0.112×10^{-4} per degree C. (0.622×10^{-5} per degree F.) in three successive runs to 600 degrees C. (1112 degrees F.), the specimen having been water quenched from 1150 degrees C. (2102 degrees F.) before the first run.

It seems probable that the cause of the variations in the coefficients of expansion in the heat-treated stainless steel are involved with the solid solution or intermetallic compound structures that are present in the alloys, in the mutual solubilities of solvent and solute, in their mutual rates of diffusion, and in the rates of formation of possible compounds at different temperatures. As a result of the determinations of coefficient of expansion, and other tests and investigations, it was decided to adopt as a standard for stainless steel trim a stainless iron containing 0.12 per cent. carbon or less, approximately 13 per cent. chromium, and no nickel. The coefficient of expansion of this metal in the state of heat treatment used in service does not vary materially on repeated heating to 600 degrees C. (1112 degrees F.), and the average coefficient of expansion in the range of from zero to 400 degrees C. (752 degrees F.) was found to be approximately 15 per cent. below the coefficient of expansion of plain carbon

steel. On the other hand, the coefficient of expansion of "Monel" metal in the same range was found to be approximately 20 per cent. above that of the plain carbon steel in question.

While these percentage differences appear large, their effect is, in reality, very slight in the actual tightening or loosening of seat ring fits due to temperature changes in service. This is on account of the limited dimensions of the parts, and it is not probable that the effect is sufficient to cause loosening or leakage if properly designed parts are used. The physical properties of this stainless iron at high temperature are better than those of "Monel" metal, and it is machinable at a Brinell hardness of 300 as compared with from 150 to 175 for "Monel" metal. It is a naturally stainless product and does not depend entirely on heat treatment and polish to resist corrosion. This material is particularly suitable for valve-stems because of its relatively low coefficient of expansion. For instance, when a valve is opened and the stem seated against the bonnet bushing, while the lower end of the stem is heated to a working temperature of say 750 degrees F., a severe tensile stress is set up in the stem by its subsequent cooling, and this is, roughly, 30 per cent. less for the grade of stainless iron discussed above than it is for "Monel" metal, due to the lower coefficient of expansion.

Taking the other case, when the valve is closed tight from the fully opened position, at which time the valve body is heated to the working temperature and the stem relatively cold, the subsequent expansion of the stem (due to heating) and contraction of the body (due to cooling) set up severe compression stresses in the stem, and here, again, the lower coefficient of expansion is a marked advantage. At the same time the coefficients of expansion of the stainless steel and the plain carbon cast-steel are sufficiently close to prevent any material change in the relative position of the disk and body when the temperatures of both the stem and body change together. Both "Monel" metal and stainless iron are standard trim materials for high-pressure, high-temperature steam service, and other trim materials may also be used in special cases.

The design and construction of a line of cast-steel globe, angle and swing check-valves for high-pressure, high-temperature steam service may also be of interest. In general, the design, materials, workmanship, inspections and tests of these valves are similar to those

used for the gate-valves just described. The bodies are spherical in form, the body necks are cylindrical and the bonnet flanges circular in order to resist deformation to the best advantage.

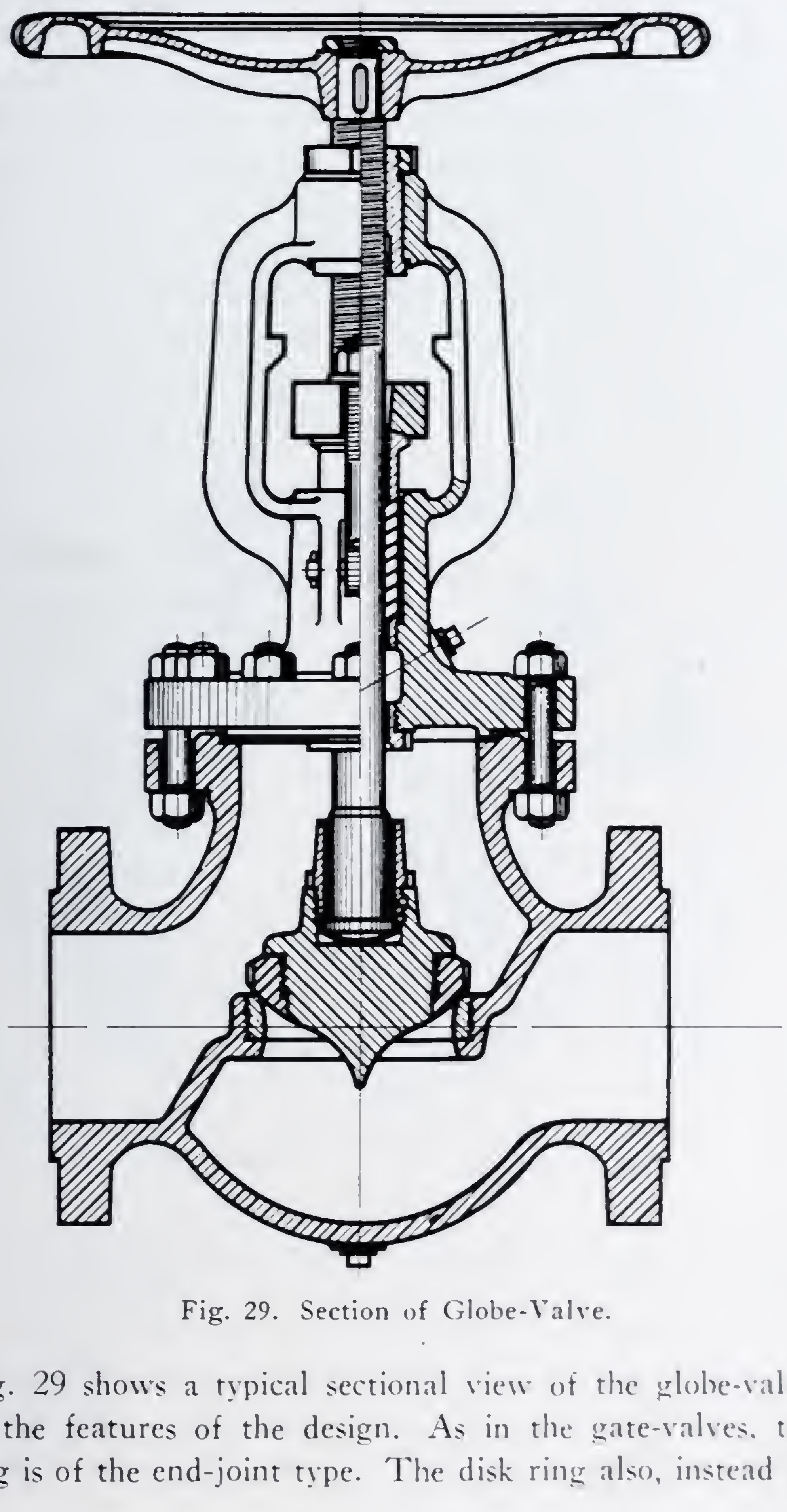

Fig. 29. Section of Globe-Valve.

Fig. 29 shows a typical sectional view of the globe-valve illustrating the features of the design. As in the gate-valves, the body seat ring is of the end-joint type. The disk ring also, instead of being

the conventional rolled-in type, is of the end-joint type, being attached to the disk with a substantial screwed connection so that it is readily renewable. Particular attention is called to the exceptionally long connection between the stem and the disk. This holds the disk accurately in alinement even when the valve is mounted with the stem horizontal. This is accomplished without resorting to a cross-bar in the body seat and lower guide for the disk, thus leaving the opening through the valve-seat free for uniform distribution of flow by the Venturi-type disk. The gradual convergence and accurate control of the direction of the flow-lines by the carefully designed contour of the disk prevents eddy-currents and their consequent evils, such as pressure drop and erosion of valve-seats. Easy curves and excess cross-sectional flow areas are provided throughout the valve.

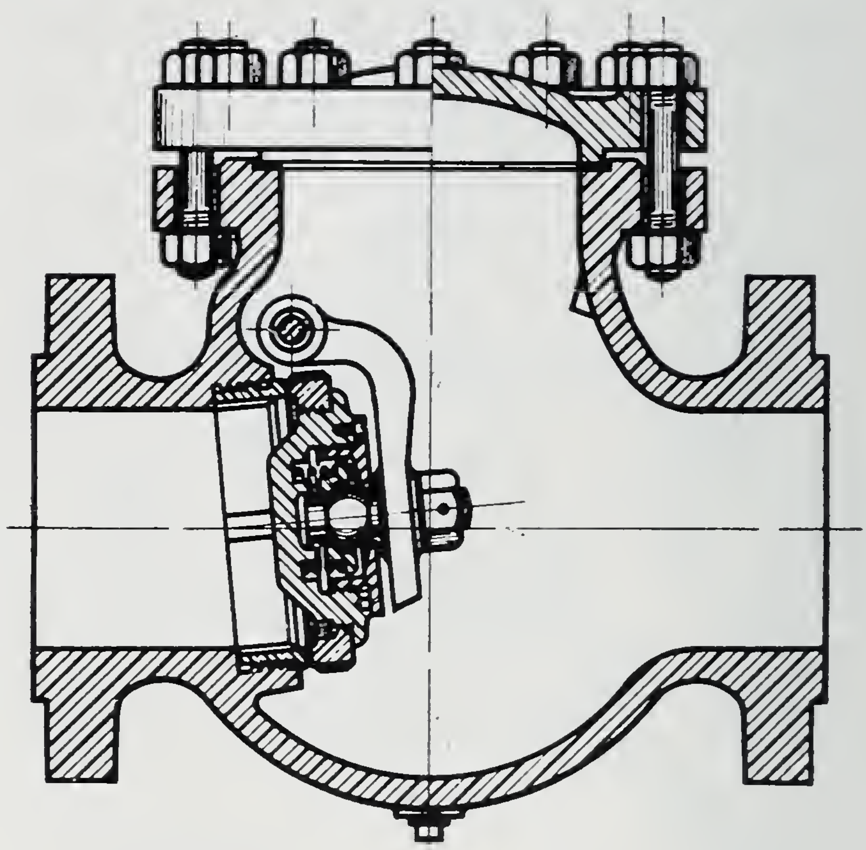

Fig. 30. Section of Swing Check-Valve.

Fig. 30 shows a typical sectional view illustrating the design of the swing check-valves of this line. The body seat ring is of the end-joint type and is screwed into a hub projecting into the valve body, thus preventing distortion or loosening due to unequal expansion under high working temperatures. The hinge pin for the disk arm is held stationary in the valve body and two renewable bushings are

provided in the arm. These are made of suitable trim material and form the rotating bearing.

Special attention is called to the connection between the disk and the disk arm. The ball-joint permits self alinement of the disk and body seat. The high-temperature spring prevents sagging of the disk in operation, and cushions the hammer blows on both the body stop at the upper end of the travel and on the valve-seat when the valve opens and closes rapidly due to pulsations in flow.

DISCUSSION

G. C. EMMONS:* How are the seats put in the valves?

F. H. MOREHEAD: The seat rings and disk rings of Walworth high-pressure valves, such as I have described here, are screwed in. The tight contact is made at the bottom of the ring and not under an overlapping collar.

G. C. EMMONS: If the customer wishes to repair the valve, how does he take the seats out and replace them with new ones?

F. H. MOREHEAD: If a shop is equipped with an angle plate with a 10-degree angle, you can replace the seats. The rings, however, are driven in by powerful machines and I question whether in any ordinary shop you can get them out without turning them out. If you have an angle plate I do not believe you will have difficulty in replacing them. Stock is provided for this purpose.

G. C. EMMONS: Some manufacturers provide lugs on the seats that they employ for screwing the seats into the body. They then very carefully turn off these lugs and make it practically impossible for the user to get the seats out in order to replace them. It is my opinion that valve manufacturers in general should give far more attention than is usually given to construction which would enable users to make proper repairs.

F. H. MOREHEAD: We leave the lugs in so that you think you can get the rings out.

*Steam and Efficiency Engineer, Republic Iron and Steel Co., Youngstown, Ohio.

J. A. Snyder:* Please tell us the objections to the square corners of the vanstone joint.

F. H. Morehead: The objections which I mentioned were that, in the opinion of some engineers, the metal in the joint is not in the same condition as it was in the original pipe. It may have been worked at a higher temperature than is necessary and there is a possibility that it may have been burned. Certainly there is an upsetting operation necessary for the production of a joint of this character. We have abandoned the use of bolts with upset heads because it was found that progressive failure sometimes occurred at the beginning of the upset, causing the bolt heads to fail.

R. W. Andrews:† I am sure we are very much indebted to Mr. Morehead for his very happily presented paper. There is just one point that I would like to have emphasized—the point he brought out to the effect that they had to make several castings before they got one for a certain job. It is very easy to design a high-class pressure station; but in the manufacture of the apparatus that has to be put in, it is not quite so simple. I know from our own experience that when we come to work on these high-pressure jobs and special equipment, the work usually costs several times what we sold it for before we get through; so that, while it may be simple to design, it is not always simple to build for that design.

Sabin Crocker:‡ Mr. Morehead criticizes the table of weights, thicknesses, and test pressures for welded and seamless pipe for high-temperature service given in Tentative Specification A 106-27 T of the American Society for Testing Materials. This table (designated as "Table I" in the above-mentioned specification) gives the dimensional data and test pressures for a series of pressure ratings corresponding to those of the Steel Flanged Standards—250, 400, 600, 900 and 1350 pounds per square inch at temperatures up to 750 degrees F. A short explanation as to the origin and basis of this table would seem to be in order.

*Chief Inspector, Hartford Steam Boiler Inspection and Insurance Co., Pittsburgh.
†Secretary and Treasurer, Andrews-Bradshaw Co., Pittsburgh.
‡Detroit Edison Company, Detroit.

In connection with the development of flange and fitting dimensions, minimum metal thicknesses, etc., for the Steel Flanged Standards, it became apparent that the wall thicknesses of pipe should also be fixed in order to secure reasonable agreement between the port openings or bore of fittings and pipe. This question first came up in the "working committee" of Subcommittee 3 on Steel Flanges and Flanged Fittings in the fall of 1923. (Subcommittee 3 is the division of the American Engineering Standards Committee's Sectional Committee on Pipe Flanges and Fittings which was charged with the development of the Steel Flanged Standards.) The working committee recommended that pipe thicknesses be determined by the modified Barlow formula of the American Society of Mechanical Engineers' Boiler Code Committee (shown on page 9 of the 1924 edition of the Boiler Code). The table referred to as "Table I" shows pipe thicknesses actually somewhat in excess of the Boiler Code requirements even after 12½ per cent. is deducted for manufacturing tolerances.

The following is quoted from the Boiler Code reference given above:

"*P-23 Thickness of Steam Piping.* In determining the thickness to be used for pipes at different pressures and for temperatures not exceeding 750 deg. fahr. for steel or iron pipe, and 406 deg. fahr. for brass and copper pipe, the following formulas are to be used:

For pipes having nominal diameters of from ¼ in. to 5 in.,

$$P = \frac{2S}{D}(t - 0.065) - 125$$

For pipes having nominal diameters over 5 in.,

$$P = \frac{2S}{D}(t - 0.1)$$

Where P = working pressure, lbs. per square inch
t = thickness of wall of pipe, in.
D = actual outside diameter of pipe, in.
S = 9000 lb. per sq. in. for seamless steel pipe
= 7000 lb. per sq. in. for lap-welded steel pipe
= 5000 lb. per sq. in. for butt-welded steel pipe"

The allowances of 0.065 inch in the first formula and 0.1 inch in the second formula are intended to compensate for the metal cut away in threading. Reference to a table of standards for pipe threads will show almost exact agreement between these allowances and the depth of thread in these sizes.

Now let us apply the first formula above to the specific case cited by Mr. Morehead where $S = 9000$; $D = 1.315$; $t = 0.133 \times 0.875 = 0.1163$ (making the allowance for 12½ per cent. under-thickness tolerance in manufacture). Then $P = \frac{2 \times 9000}{1.315} (0.1163 - 0.065) - 125 = 577$ pounds per square inch. In other words, after taking into account the metal removed in threading, the Boiler Code would allow 577 pounds per square inch working pressure for this one-inch pipe of the 400-pound seamless column in the table.

From a standpoint of bursting pressure alone, the pipe thicknesses given in the table are unquestionably sufficient in all cases even when the 12½ per cent. manufacturing tolerance is deducted and American Standard pipe-threads are cut in the pipe. In the case of threaded 400-pound seamless pipe, however, the total combined stresses to be expected from internal pressure, thermal expansion, dead weight between supports, etc., seem excessive for the amount of metal left at the bottom of the threads. Or, to consider the matter for the moment from the viewpoint of practical experience, the metal left after threading 400-pound seamless pipe does not seem to furnish sufficient mechanical strength for the service. The condition of excessive weakening due to threading appears to be limited to 400-pound seamless pipe, and the writer questions whether Mr. Morehead intends his criticism to cover more than this one class of pipe.

Very little, if any, threaded pipe will be used in sizes larger than three inches. There seems to be no question but that the thicknesses given are adequate for the corresponding pressures where pipe is not threaded. The writer would suggest that the fault which Mr. Morehead finds with the table can be remedied by adding a foot-note at the bottom of the table recommending that where threaded pipe is desired for working steam pressures approaching 400 pounds, the 600-pound weight of pipe shall be used.

In spite of the caustic comments made by Mr. Morehead with reference to the table and the various committees which had a hand in its preparation, it is a fact that for upwards of four years he has been a member (or has represented a member) on both the American Engineering Standards Committee and American Society for Testing Materials committees concerned with the development of specification A 106-27 T and its "Table I." The writer also has been a member

(or served as alternate) on these same committees since their organization, and to the best of his knowledge Mr. Morehead has neither specifically criticized "Table I" to either committee nor offered any constructive suggestion for its improvement. If the situation is really as bad as Mr. Morehead seems to feel, it seems reasonable to ask why he has not voiced this opinion in the meetings of the committees responsible for the preparation and publication of this table instead of attempting to discredit the work of these committees by a public utterance at this late date.

F. H. Morehead: Mr. Crocker's first reference is to the writer's criticism of "Table I," as included in current publication of the American Society for Testing Materials specification A 106 on "Piping Materials for High-Temperature Service." Mr. Crocker has explained that this table was tabulated according to Barlow's modified formula as used by the Boiler Code Committee of the American Society of Mechanical Engineers.

I have no disagreement with Mr. Crocker in this respect, nor with respect to the fact that in theory, and considering bursting pressure only, the pipe is sufficiently strong even though it be threaded.

As pointed out in the paper, the unfortunate part about the table is the fact that the material specified is not sufficiently strong when threaded to withstand all the other strains to which piping for high-temperature service is invariably subjected.

I have discussed this table with a member of the Boiler Code Committee. The Boiler Code Committee, according to this member, also sees objection to the table as printed, partly based on the likelihood that seamless tubing may be made from material capable of withstanding a higher safe working stress than 9000 pounds per square inch. I can therefore only agree with Mr. Crocker's statement as follows:

> "Or, to consider the matter for the moment from the viewpoint of practical experience, the metal left after threading 400-pound seamless pipe does not seem to furnish sufficient mechanical strength for the service."

While I made a specific instance of the smaller sizes under the 400-pound heading, I did not and do not intend to limit my criticism of this table to this section. I object first to the fact that the table appears in this specification in any form. If it is wrong with respect

to the smaller sizes of 400-pound pipe, why may it not be wrong with respect to other sizes for other pressures? There are undoubtedly many things which could be done to the table in the way of correction.

Mr. Crocker traces the origin of the table from a sub-sub-committee of the American Engineering Standards Committee's Sectional Committee on Pipe Flanges and Fittings. Mr. Crocker dates this beginning back to 1923. "Table I," however, did not actually come into existence officially until the January 13 meeting of the American Society for Testing Materials' Subcommittee 22 of A 1, which is the working committee dealing with the pipe specification. This table had previously been sent out to the members of the committee and perhaps also to members of certain committees of the American Engineering Standards Committee by Mr. Crocker.

I am sure that Mr. Crocker will remember a number of instances in which criticism of the table was voiced. One criticism which I have made both in Committee 22 and in the American Engineering Standards Committee's Sectional Committee is to the effect that this table as drawn up does not specify minimum acceptable thicknesses, but rather does specify quantities 12½ per cent. above the acceptable minimum, and on this account the values are presumably subject to a reduction of slightly more than 11 per cent. in order to arrive at the true minimum. All other dimensions which are subject to variation in manufacturing tolerances which appear in American standards for material of this sort are given as minimum.

I quote below a letter written by myself to Mr. Crocker on April 2, 1926. Perhaps this letter will refresh Mr. Crocker's memory as to whether or not I have previously voiced criticism of the table.

"April 2, 1926.

Mr. Sabin Crocker
Detroit Edison Company
2000 Second Avenue
Detroit
Michigan

My dear Crocker:

You will remember some time ago having sent out a comparison of port openings of pipe and fittings in blueprint form. I have just now had an opportunity to sit down and study this through. You give the inside diameter of 14" seamless open hearth pipe for 600 lbs. pressure as 13.6875. This is obviously an error and should be 12.6875. This reduces the discrepancy in

port diameters on this size of fitting from .8125 to .188, and, to my way of thinking, really clears up the situation.

I cannot bring myself to agree with you on the publication of the table of dimensions on which this print above mentioned is based. I realize that the National Tube Company has stated that it is impossible to produce seamless drawn tubing and guarantee that it will not run under the specified thickness by an amount approximating 12½%. This is probably true insofar as information in hand at the National Tube Company is available. I do not believe, however, that the last word on seamless tubing has been spoken. I repeat the statement which I made at Providence which was to the effect that it is entirely likely that within a reasonable time seamless drawn tubing will be produced by methods not now contemplated which will result in uniformity of wall thicknesses not possible by present methods.

Then, again, the publication of this table with an allowance below specified thicknesses of 12½% is not according to the precedent established on other phases of the standards—that is, castings dimensions.

Yours truly,

WALWORTH COMPANY,

F. H. MOREHEAD, Chief Engineer."

Following this same line of thought, I quote below a paragraph from the minutes of the meeting of the American Society for Testing Materials Committee A 1, held at French Lick, Ind., on June 21, 1927. Mr. Crocker will be able to gather from this paragraph that I continued to protest the inclusion of this table in this specification.

"ITEM VI—NEW BUSINESS

(a) The Secretary read a letter from the Manufacturers' Standardization Society criticising the existence of a table of dimensions, etc., of pipe in Specification A 106 26T.

As this specification is tentative and is not proposed for advancement to standard this year, the letter was referred to the Chairman of Sub-Committee XXII for the consideration of his committee during the year. This action was satisfactory to Mr. Morehead, spokesman for the Manufacturers' Standardization Society."

I will further insert a paragraph from the minutes of the American Engineering Standards Committee's working committee meeting of Subcommittee 3, which Mr. Crocker indicates as having originated "Table I."

"It was moved by Mr. Burritt, seconded by Mr. Tanner, that table No. 1 of dimensions and weights of pipe for 250, 400, 600, 900 and 1350 pounds for high temperatures, which appears in the proof sheets of the A.S.T.M. proposed specifications, be added as an appendix to our specifica-

tions, and that a footnote be attached to this table stating that all mill tolerances have already been added. Carried."

A verbatim report of the discussion surrounding the above motion would indicate that in this committee also certain objections were raised to this table. It would seem then that "Table I" first officially appeared in a specification of the American Society for Testing Materials, and that it was adopted by the American Engineering Standards Committee from American Society for Testing Materials proof sheets.

The table did not appear in the February 1926 preprint of the Tentative Standard for Steel Pipe Flanges and Flanged Fittings. Its first appearance in the Standard was in the August 1926 preprint.

I wish in concluding to point out to Mr. Crocker that a criticism of a tentative specification is in no way an attempt "to discredit the work of those committees by a public utterance at this late date."

It is my understanding that the sole reason for publishing specifications and standards as tentative is to invite criticism, whether publicly uttered or privately written. In other words, as long as a standard remains tentative, the open season is on.

GENERAL INDEX

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Tuesday, January 18, at 4:10 P. M., President W. E. Fohl presiding, Messrs. Ladd, Hunter, Weldin, Clifford, Edgar, Spellmire, Forsberg, Hopkins, Rice, Humphrey, Johnston, Covell and the Secretary being present.

The minutes of the last meeting, held December 14, were approved without reading.

Applications for membership having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Fairchild, F. P.	Flippen, J. P.
Fusca, Emil A.	Hester, E. A.
Jobke, August F.	Furlow, James W.
Robertson, Ralph N.	Umstead, Elgie James

Whyte, Clifford R.

ASSOCIATE

Hacking, J. P.

JUNIOR

Fiedler, Marcell

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Billheimer, C. R.	Lewis, Essington
Caffall, Geoffrey Arthur	Olson, Harold Marinius
Dake, Virgil Hungerford	Robertson, David
Desch, John Leo	Young, Lewis E.

ASSOCIATE MEMBERS

Bradshaw, William Daniel	Provan, John Stevenson
McKown, Howard Purcell	Todd, C. L.

JUNIOR

Burgess, Henry Russell

Application for transfer was received from Mr. William E. Homer, and the Secretary was requested to advise him of his transfer to the grade of Member.

Death of the following members was reported by the Secretary:

C. S. Cook..........	Joined March, 1924	Died Nov. 15, 1926
H. C. Lyons........	Joined Sept., 1923	Died Dec. 30, 1926
F. I. Ellis.............	Joined Feb., 1902	Died Jan. 16, 1927

In connection with the death of Mr. Ellis, it was regularly moved and carried that Mr. George T. Ladd and Mr. F. C. Biggert be appointed a special committee to prepare a memoir of Mr. Ellis. The Secretary was also instructed to write a letter of sympathy to the family.

The report of the Secretary, showing the financial condition of the Society at the close of business December 31, having been audited by the Finance Committee, was approved.

The Secretary reported that the accounts of the Society had been audited by the certified public accountant in accordance with our usual custom and

the accounts found to be correct as reported monthly to the Board. Due to increased activities during the past year, we did not finish the year financially in as good condition as last year. However, the bills have all been paid to December 31, with the exception of the November and December issues of the PROCEEDINGS, which have not as yet been printed. The budget was lived up to with the exception of the item "Office and Miscellaneous," which was over to the extent of $600, accounted for mainly by the purchase of a year's supply of playing cards, which were purchased by the Finance Committee in large lots much cheaper than we had heretofore. We also had some additional speakers' expenses which, together with the cards, totaled very close to $600.

Mr. Clifford, Chairman of the Entertainment Committee, reported that arrangements were completed for the Annual Dinner and that the seating capacity was practically reached at this time. He reported further that the Committee had made tentative arrangements for a Ladies' Night party to be held the latter part of February.

The Membership Committee held one meeting during the month and transacted the usual routine business of the Committee.

The Secretary presented the following letter from the Cleveland Engineering Society:

December 13, 1926.

Engineers' Society of Western Pennsylvania,
Pittsburgh, Pa.

GENTLEMEN—As you are aware, many engineers by necessity are shifting their business headquarters frequently from one city to another. Many of these men never feel sufficiently settled in one place to warrant their joining a local society because they feel that as soon as they move they will have to start all over again in their new location.

We believe that if you in Pittsburgh could tell prospective members of this sort that should they move to Cleveland they would have no further initiation fee to pay, but would merely have to make out a formal application for membership and take up their dues in the Cleveland Engineering Society when their dues in the Engineers' Society of Western Pennsylvania expire, the majority of them would be glad to join your organization on this basis.

As a matter of fact, the Cleveland Engineering Society is very glad to do just this for the members of any other local society who will do the same for our members moving to their districts. This is provided for in our Constitution as follows: "Any member in good standing of any local engineering society or technical society in United States or Canada, which grants members of this society a similar privilege, may become a member of this society on his application and election as provided for other applicants for membership, but without payment of entrance fee. The dues of a member so transferred shall be credited to the date to which they have been paid in the society from which the transfer is made, but not for a longer period than one year from date of transfer."

In the long run we believe a reciprocal arrangement of this sort will help very materially in building up our local societies. We would be very glad, therefore, to have the Engineers' Society of Western Pennsylvania take up this matter and hope that you may see fit to adopt the reciprocal arrangement of this sort in due time.

Yours very truly,

THE CLEVELAND ENGINEERING SOCIETY,
(Signed) C. R. SABIN, *Secretary-Treasurer.*

After discussion, it was moved and carried that this matter be referred to the Membership Committee with the request that they report back at the next meeting of the Board.

The meeting adjourned at 5:30 P. M.

K. F. TRESCHOW, *Secretary.*

CIVIL SECTION—ANNUAL MEETING

The annual meeting of the Civil Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, January 4, at 8 P. M., Chairman V. R. Covell presiding, 68 members and visitors being present.

The minutes of the last meeting were read and approved.

The annual report of the Chairman was read by the Secretary.

The report of the Nominating Committee was presented by the Secretary, as follows:

December 29, 1926.

Officers and Members, Civil Section:

DEAR SIRS—Your Nominating Committee, appointed to nominate officers for the Civil Section for the ensuing year, met to-day at 12:30 and nominated the following:

R. P. Forsberg .... Chairman
C. S. Davis .... Vice Chairman
J. F. Laboon
C. M. Reppert
C. N. Haggart .... Directors
J. L. deVou
T. B. Sturgess

Respectfully submitted,
LOUIS P. BLUM, *Chairman,*
W. H. BUENTE,
B. A. LUDGATE,
Nominating Committee.

On motion, nominations were closed and the Secretary requested to cast an unanimous ballot for the nominees, who were thereupon declared elected.

Mr. Forsberg, the Chairman-elect, then took the chair.

No further business coming before the Section, the paper of the evening, on "Recent Trend in Sewage Disposal Developed in Design for Fostoria, Ohio," was presented by Mr. J. F. Laboon, member of firm, J. N. Chester, Engineers, Pittsburgh, Pa.

The ensuing discussion was participated in by: J. T. Campbell, member of firm, J. N. Chester, Engineers; N. B. Jacobs, Treas., Morris Knowles, Inc.; G. T. Pettay, Aires, Stone & Pettay; P. W. Price, Prin. Asst. Engr., Bureau of Bridges, Dept. Public Works, Allegheny County; P. S. Wickerham, Consulting Civil Engineer, Butler, Pa.; and the author.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. Laboon for his very interesting and instructive paper.

The meeting adjourned at 10:05 P. M.

K. F. TRESCHOW, *Secretary.*

JOINT MEETING ELECTRICAL SECTION, E. S. OF W. PA., AND PITTSBURGH SECTION, A. I. E. E.

The regular monthly meeting of the Electrical Section of the Engineers' Society of Western Pennsylvania was held jointly with the Pittsburgh Section of the American Institute of Electrical Engineers in the auditorium of the Chamber of Commerce, Tuesday, January 11, at 8:10 P. M., Chairman George S. Humphrey and D. M. Simons, Chairman of the Pittsburgh Section of the A. I. E. E., presiding, 350 members and visitors being present.

The reading of the minutes of the last meeting was dispensed with.

A committee to nominate officers for the ensuing year was appointed by the Chairman, as follows: G. E. Stoltz, Chairman; J. M. Miller, R. L. Kirk.

No further business coming before the Section, the papers of the evening were presented by L. P. Peck, American Brown-Boveri Electric Company; W. B. Spellmire, Manager, General Electric Company, and F. D. Newbury, Manager, Power Engineering Department, Westinghouse Electric & Manufacturing Company, on "The Trend in Large Turbo-Generator Development."

A general discussion followed the presentation of the papers.

On motion, duly seconded and carried, a vote of thanks was extended to the speakers for their very interesting and instructive papers.

The meeting adjourned at 9:45 P. M.

K. F. Treschow, *Secretary.*

ANNUAL MEETING

The forty-seventh annual meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, January 18, at 8:18 P. M., President W. E. Fohl presiding, 38 members and visitors being present.

The minutes of the last annual meeting, held January 19, were read and approved.

The annual report of the Board of Direction, which included the reports of the Standing Committees, the Sections and the Treasurer, was read, as follows:

REPORT OF BOARD OF DIRECTION

"During the year ten meetings of the Board of Direction were held and one special meeting, at which the routine business of the Society was transacted.

"During the year there were eight regular meetings and the annual meeting of the Society. The total attendance was 1430, the average being 160. The maximum attendance was 500, at the December meeting, and the minimum 38, at the November meeting. There was a general discussion at each of the meetings.

"The Board wishes to again call the attention of the members to the increased activities of our Society, as mentioned in the report of the Entertainment and Finance Committees, and desires to emphasize the importance of comments, either favorable or unfavorable, from the membership on the work we are doing.

"All of the committees are endeavoring to give you those activities in which you are interested and, as our finances must be watched carefully, it is important that we know your desires.

"The attendance in our clubroom is increasing steadily, as is the number taking advantage of the engineers' table in the cafeteria.

"It might also be well to call your attention to the fact that in our present location we are giving practically all the privileges of a club, and we hope that our members will take advantage of them."

Respectfully submitted,

K. F. Treschow, *Secretary.*

REPORT OF ENTERTAINMENT COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

Dear Sirs:

The following entertainments and inspection trips were held during the year 1926:

January 25—Annual Banquet. Attendance 1154.

February 19—First Annual Open House and Ladies' Night. Attendance 104.

March 19—Concert of Engineers' Society Quartet. Attendance 20.

March 5 to April 30—Sixth Annual Chess Tournament. Attendance 30. Cup won by Mr. E. D. Leland.

May 1—Inspection Trip to Cleveland. W. S. Tyler Company, Cleveland Electric Illuminating Company, and dinner and smoker in evening. Attendance 30.

June 18, July 20 and September 17—Third Annual Golf Tournament. June 18, Shannopin Country Club; attendance 30. July 20, Edgewood Country Club; attendance 30. September 17, Pittsburgh Field Club; attendance 30. Cup won by Mr. I. D. Goodwin.

November 8—Ladies' Night Party—Calendar Party. Attendance 190.

December 3—Inspection Trip. Large electric locomotives. Westinghouse Electric & Manufacturing Company. Attendance 40.

Reservations indicate that we will have a large attendance at the banquet this year.

Respectfully submitted,

T. C. Clifford, *Chairman.*

REPORT OF FINANCE COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

Dear Sirs:

In accordance with the established custom, an independent audit of the Society's accounts was made this year by Mr. William B. Hanson, certified public accountant. This audit shows that the statements which have been rendered monthly were correct. A study of this audit indicates that, in accordance with the policy of the Board in adopting the 1926 budget, our various activities have been increased during the past year, with the result that, while we received more money during this year, we did not have the net income at the close of the year that we had in 1925. It will, therefore, be necessary during the year 1927 to carefully analyze the work done during the past year and continue only those activities in which the membership seemed to be interested.

At the January meeting of the Board the Secretary was authorized to transfer $1,000 from our General Fund to the Permanent Fund to repay in

part the loan made from this fund several years ago, and this brings the balance owing this fund to $1,845.

The Finance Committee early in the year called the attention of the Board to the fact that there was an accumulation of about $7,000 cash in our Permanent Fund and recommended that this amount be invested in bonds. The Board authorized the Committee to purchase $6,000 worth of bonds, and after careful investigation the following were purchased and have been deposited in our safe deposit box: Two Wheeling Steel Corporation 5½ per cent., two McKeesport Tin Plate Company 6 per cent., and two Baltimore & Ohio Railroad 5 per cent. The total cost of these bonds was $5,965.17.

In general, the finances of the Society are in good condition, although, as stated above, with the formation of two new sections and our other activities, it is important that we carry on only those functions in which we feel there is a general interest, and it might be well at this time to urge the members of the Society to assist the Board and the Chairmen of the various committees by sending in suggestions as to the activities in which you are interested and, further, by supporting the Society by your attendance at the functions held during the year.

Respectfully submitted,

JOHN A. HUNTER, *Chairman.*

REPORT OF HOUSE COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

The House Committee begs to report the following for the year 1926:

According to the Secretary's records, there was an attendance of 5062 for the year, an increase of 789 over 1925. The increase last year was 417 over the year previous. The Committee regards these figures as satisfactory evidence of the policy of the Board in increasing, so far as possible, the club facilities and the attractiveness of the rooms.

A new motion picture screen and a new bulletin board were purchased during the year on the recommendation of the Committee. On the approval of the Board of Direction, the Committee authorized the Secretary to sign a lease for the coming year at an increase of $50 per month.

The Committee attacked an unsatisfactory condition of the ventilation of the rooms, which is particularly noticeable in the summer. Through the courtesy of Mr. Downes, of the American Blower Company, anemometer and smoke tests were made in the rooms, which disclosed two facts. First, that in the lounge room the amount of air exhausted was only about half of the amount supplied, the remaining half being obliged to find its way out by the doorway; and second, that some of the air supplied by new grills near the ceiling was short-circuited by the outlets in the ceiling without benefiting the living conditions.

A detailed sketch showed the exact conditions at each grill, and this was studied by the Committee under the advice of Mr. Downes and Mr. McGonagle, of our Society, and through the co-operation of Mr. McGarvey, of the Society, who is mechanical engineer for the hotel, certain duct changes were made and a new exhaust fan was installed having a capacity of 10,000 cubic feet of air per minute. There was also installed eight 1000-watt heating strips in the ducts supplying air to the rooms so as to remove discomfort from incoming air.

The new arrangements seem to have improved the ventilation conditions materially and have removed the objectionable odor heretofore noticed, but

the Committee would like to mention that the real test of the ventilation will come in the hot summer weather and the then House Committee should review conditions and, if necessary, have further adjustments made.

We wish to express our appreciation of the prompt and hearty co-operation of Mr. McGarvey and the hotel management in remedying this condition as soon as a definite proposition was put up to them.

In September an experiment was made, by approval of the Board, by allowing the Alumni Association of State College to receive returns from certain football games on two Saturday afternoons. The Association paid $20 each time for this privilege, and the function was well attended, well liked and apparently did not seriously interfere with the regular use of the rooms. It is thought that occasional use of the rooms of this kind may bring to us some new members, but caution will have to be exercised lest this practice grow to the detriment of the regular use of the clubrooms.

Respectfully submitted,

R. P. Forsberg,
C. M. Reppert,
W. A. Inrgam,
W. A. Weldin, *Chairman,*
House Committee.

REPORT OF MEMBERSHIP COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

Dear Sirs:

Ten meetings of the Committee were held during the year to assign the applications to the various grades of membership and to transact any other business coming before the Committee.

A letter of invitation was sent to all the local members of the American Institute of Electrical Engineers and cards were received from 30 members accepting our invitation to join the Society.

Two hundred and fifty-one new members were elected during the year, and the membership is now about 1641.

The assistance and co-operation of the men making up the Membership Committee are gratefully acknowledged. At the close of the year the membership of the Society was as follows:

Honorary Members	1
Members	1266
Associate Members	162
Associates	93
Juniors	108
Student Juniors	8
	1638
Dropped	49
Resigned	54
Died	23
Accessions	251

Respectfully submitted,

W. L. Affelder, *Chairman.*

REPORT OF PUBLICATION COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

Dear Sirs:

Three meetings of the Committee were held during the year, with an average attendance of four.

Papers presented at the general Society meetings	9
Papers presented at the Section meetings	25

Three meetings of the Practicing Engineers' Section were held, at which routine business of the Section was discussed. The Section also concerned itself with the elimination of unprofessional practices; enforcement of the Engineers' Registration Law; a program for the education of the public in the work of the engineer; and improvement of the practice of engineering in surveys and records.

Two new sections were formed during the year—an Electrical Section and an Illuminating Engineers' Section.

Twenty of the papers presented have been published in the Proceedings, or will be published later.

Respectfully submitted,
G. M. Goodspeed, *Chairman.*

REPORT OF TREASURER

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

Dear Sirs:

Your Treasurer desires leave to submit the following report for the year 1926:

RECEIPTS

Dues Collected	$18,964.81	
Entrance Fees	815.00	
Sale of Advertising Space	4,899.03	
Sale of Magazine Proceedings	826.83	
Sale of Society Pins	114.00	
Interest on Bonds	834.83	
Interest on Bank Balance	343.89	
Income on Banquet	7,392.00	
Inspection Trip Collections	635.52	
Ladies' Night Entertainments	368.50	
Golf Tournament	522.97	
Sale of Concert Tickets	61.50	
Practicing Engineers' Dinners	49.75	
Joint Meeting with A. S. M. E.	79.50	
Steel Works Section Conference	191.50	
Civil Section Conference	101.50	
Mechanical Section Conference	86.50	
Rentals Received from Clubroom	40.00	
Miscellaneous	55.98	
		$36,383.61

DISBURSEMENTS

Administrative and General	$20,862.89	
Cost of Magazine PROCEEDINGS	5,916.42	
Furniture and Fixtures	186.02	
Concert Expenditures	153.00	
Ladies' Night Entertainments	881.03	
Golf Tournament	850.82	
Practicing Engineers' Dinners	62.00	
Civil Section Conference	300.00	
Steel Works Section Conference	389.35	
Inspection Trips	938.82	
Mechanical Section Conference	69.50	
Annual Banquet—1926	6,608.23	
Annual Banquet—1927	254.30	
Investment—Bonds	5,890.00	
		$43,362.38

CASH ASSETS

	Dec. 31, 1925	Dec. 31, 1926
Permanent Fund—		
Bonds	$13,807.50	$20,127.50
Cash—Fidelity Title & Trust Co	5,094.71	849.54
Reserve Fund—		
Cash—Fidelity Title & Trust Co	2,500.00	2,500.00
General Fund—		
Cash—First National Bank	2,214.66	246.03
	$23,616.87	$23,723.07
Increase in Assets	109.20	
	$23,723.07	

One $1,000 Butler Water Co. 30-Year Bond, maturing September 2, 1931, No. 9	$ 965.00
Two $1,000 Connellsville Water Co. 5 Per Cent., Nos. 317-318, maturing October 1, 1939	1,840.00
Two $1,000 Portsmouth, Berkley & Suffolk Water Co. 5 Per Cent., Nos. 465-66, maturing November 1, 1944	1,970.00
Two $1,000 Jamison Coal & Coke Co. 5 Per Cent., Nos. 1502-03, maturing May 1, 1931	2,000.00
Two $1,000 Union Steel Co. 5 Per Cent., Nos. 38642-38643, maturing December 1, 1952	2,180.00
Two $1,000 Pennsylvania R. R. 4½ Per Cent., Nos. 27320-27321, maturing August 1, 1960	2,040.00
Three $1,000 Jones & Laughlin Steel Corporation 5 Per Cent., Nos 3020-21-22, maturing May 1, 1939	3,097.50
Two $1,000 Baltimore & Ohio R. R. 5 Per Cent., Nos. 28671-2, maturing March 1, 2000	2,035.00
Two $1,000 McKeesport Tin Plate 6 Per Cent., Nos. 5773-4, maturing March 1, 1946	2,060.00
Two $1,000 Wheeling Steel Corporation 5½ Per Cent., Nos. 8518-9, maturing July 1, 1948	1,940.00
Total Securities Owned	$20,127.50

I am glad to state that the market value of all bonds owned by the Society have increased in value $430 during the past year.

Respectfully submitted,

A. STUCKI, *Treasurer.*

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

I wish to submit a report of the work done by the Civil Section during the year 1926.

Four meetings of the Section were held, one being the annual meeting and one the all-day conference. The average attendance was 118, the maximum being at the March 2 meeting, with an attendance of 225, and the minimum at the January 5 meeting, with an attendance of 50. An average number discussing papers was eight.

January 5—Annual meeting. "Final Report on Local Aggregates for Concrete," by C. S. Davis, Chairman, Committee and Consulting Engineer.

March 2—"Report on Local Aggregates for Concrete," by C. S. Davis, Chairman Committee and Consulting Engineer.

May 4—"Highway Location and Construction," by S. W. Jackson, Division Engineer, Pennsylvania Department of Highways, Greensburg, Pa.

November 4—All-day conference. "Evolution of Steel Skeleton Type of Building," by Robins Fleming, Structural Engineer, American Bridge Company, New York City; "Recent Development of Rolled Structural Sections," by A. E. Crockett, Manager, Bureau of Instruction, Jones & Laughlin Steel Corporation; "Foundations," by G. R. Johnson, Vice President, The Foundation Company, Pittsburgh, Pa.; "Effect of Gunite Incasement on Structural Steel," by B. C. Collier, President, Cement Gun Company, Incorporated, Allentown, Pa.

Respectfully submitted,
V. R. COVELL, *Chairman.*

REPORT OF ELECTRICAL SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

I wish to report on the work done by the Electrical Section during the year 1926, as follows:

The organization meeting was held March 31, 1926, and four other meetings were held, the maximum attendance being at the October 12 meeting, with 510, and the minimum being at the March 31 meeting, with an attendance of 95.

March 31—Organization meeting. "Superpower—the Giant Killer," by R. F. Schuchardt, Commonwealth Edison Company, Chicago, Ill.

September 14—"New Landmarks in Electrical Communication," by Paul B. Findley, Electrical Engineer, Bell Telephone Laboratories.

October 12—"Automatic Train Control," by L. F. Howard, Chief Engineer, Union Switch & Signal Company, Swissvale, Pa.

November 9—"Economic Conditions Affecting the Electrical Business in Some of the World's Markets," by S. L. Nicholson, Vice President, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

December 14—"Research," by Dr. W. R. Whitney, Director, Research Laboratory, General Electric Company, Schenectady, N. Y.

All meetings were held jointly with the Pittsburgh Section of the A. I. E. E.

Respectfully submitted,
G. S. HUMPHREY, *Chairman.*

REPORT OF MECHANICAL SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

I submit herewith report of the work done by the Mechanical Section during the year 1926.

Five meetings of the Section were held, one being the annual meeting and one the all-day conference, this being the first all-day conference held by the Section. The maximum attendance was 78, at the October 5 meeting, and the minimum 25, at the June 1 meeting. An average of eight participated in the discussion. There was an average attendance of 56. All meetings, except the annual meeting, were held jointly with the Pittsburgh Section of the A. S. M. E.

February 2—Annual meeting. "Fuels in Industry," by H. H. Clark, Industrial Gas Engineer, Peoples Gas, Light & Coke Company, Chicago, Ill.

April 7—"Automatic Control of Combustion," by T. A. Peebles, Chief Engineer, The Hagan Corporation.

June 1—"Furmanite—Its Uses and Advantages," by Oliver L. Gilbert, Sattley & Gilbert, Sales Agents, The Furmanite Corporation, Newport News, Va.

October 5—"Design of High-Pressure Industrial Power Plants," by R. S. Bayntun, The Chesapeake Corporation, West Point, Va.

December 16—All-day conference. "Small Turbines," by George A. Orrok, Consulting Engineer, New York City, N. Y.; "Boiler Settings," by G. E. Dignan, Chief Engineer, Rust Engineering Company; "Characteristics of Fans," by T. G. Estep, Assistant Professor, Mechanical Engineering, Carnegie Institute of Technology.

Respectfully submitted,
WILLIAM SHAW, *Chairman.*

REPORT OF MINING SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

I submit the report of work done by the Mining Section during the year 1926, as follows:

Three meetings of the Section were held during the year, one being the annual meeting. There was an average attendance of 34, the maximum being 45, at the January 26 meeting, and the minimum being 15, at the September 28 meeting. An average of seven discussed the papers presented.

January 26—Annual meeting. "Mining for Oil," by Dr. R. E. Somers, Professor of Geology, University of Pittsburgh.

March 30—"Various Methods of Cutting Coal," by W. R. Jarvis, District Manager, Sullivan Machinery Company.

September 28—"Mine Timber Standardization from Standpoint of the Manufacturer," by Ralph A. Smith, Secretary, Pennsylvania Forest Products Manufacturers' Association, Tyrone, Pa.

Respectfully submitted,
N. F. HOPKINS, *Chairman.*

REPORT OF PRACTICING ENGINEERS' SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

I wish to submit herewith report of the Practicing Engineers' Section of the work done during the year 1926, as follows:

Three meetings of the Section were held. The attendance was 18 at the February meeting, 16 at the May 26 meeting, and 14 at the November meeting.

The Section concerned itself with the elimination of unprofessional practices; enforcement of the Engineers' Registration Law; a program for educating the public in the work of the engineer; and improvement of the practice of engineering in surveys and records.

The By-Laws of the Section were amended to read that the Section would hold its meetings on the second Wednesday of February, May and November, and special meetings at the call of the Chairman.

Respectfully submitted,

J. M. RICE, *Chairman.*

REPORT OF STEEL WORKS SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

I wish to submit herewith report of the Steel Works Section of the work done during the year 1926.

Three meetings of the Section were held during the year, one the annual meeting and one an all-day conference. The average attendance at these meetings was 93, the maximum being at the October 28 meeting with an attendance of 150, and the minimum at the April 27 meeting with an attendance of 60. The average number discussing papers were 10. The papers presented were:

February 23, 1926—Annual meeting. "Steel Plant Operating Costs from an Engineering Point of View," by L. C. Edgar, Chief Engineer, Edgar Thomson Works, Carnegie Steel Company.

April 27—"Gas Scrubbing in the Steel Industry," by W. G. McGurty, Engineer, Bartlett-Hayward Company, Baltimore, Md.

October 28—All-day conference. "Recuperators for Industrial Furnaces," by Willibald Trinks, Consulting Engineer and Professor, Mechanical Engineering, Carnegie Institute of Technology; "Recuperators Applied to Open-Hearth Furnaces," by E. H. Fitch, Consulting Engineer, Allentown, Pa.; "Air Preheaters for Boilers," by R. E. Butler, Engineer, Babcock & Wilcox Company, Pittsburgh, Pa.

This is the second all-day conference held by the Steel Works Section.

Respectfully submitted,

A. C. FIELDNER, *Chairman.*

The report of the tellers was presented by Mr. Van A. Reed, Jr., Chairman, as follows:

To the Members,
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

The undersigned tellers publicly canvassed the ballots in the annual election of officers of the Society at noon, Tuesday, January 18, 1927, and wish to report the following:

Ballots received	422
Irregular ballots	5
Ballots counted	427

For President	George T. Ladd	419
For Vice President	J. N. Chester	409
For Treasurer	A. Stucki	422
For Directors	V. R. Covell	422
	A. C. Fieldner	419

Respectfully submitted,

VAN A. REED, JR., *Chairman,*
D. D. PENDLETON,
T. H. THORN, *Tellers.*

The President thereupon declared the following gentlemen elected:

For President	George T. Ladd
For Vice President	J. N. Chester
For Treasurer	A. Stucki
For Directors	V. R. Covell
	A. C. Fieldner

Past Presidents Taylor and Spellmire escorted the President-elect to the chair.

Past President Fohl: "It gives me great pleasure to place in your hands this emblem of your authority as the duly elected and installed President of this Society. I hope you enjoy your period of service as much as I have enjoyed mine. And I congratulate the members of the Society upon their discrimination in choosing you for this service."

President George T. Ladd: "Gentlemen, I want to take this opportunity to express my deep appreciation of the honor you have conferred upon me, and I wish to assure you that during the year 1927 I will do my best to promote the Engineers' Society of Western Pennsylvania."

No further business coming before the meeting, the retiring President's address was presented, on "Recovery of Petroleum and Natural Gas Through Overlying Coal Beds," by William E. Fohl, Consulting Engineer, Pittsburgh.

A vote of thanks was extended to Mr. Fohl for his very interesting and instructive paper.

On motion, the meeting adjourned at 9:25 P. M.

K. F. TRESCHOW, *Secretary.*

MINING SECTION—ANNUAL MEETING

The annual meeting of the Mining Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, January 25, at 8:20 P. M., Chairman N. F. Hopkins presiding, 35 members and visitors being present.

The minutes of the last annual meeting were read and approved.

The annual report of the Chairman was read by the Secretary.

The report of the Nominating Committee was presented as follows:

To Members and Officers, Mining Section:

DEAR SIRS—Your Nominating Committee appointed to nominate officers for the Mining Section for the ensuing year held a meeting Tuesday, January 25, and submit the following members:

C. E. Lesher .... Chairman
L. O. Lougee .... Vice Chairman
Joseph Bryan
R. E. Davis
M. D. Gibson
W. M. Jarvis
J. A. Malady } .... Directors

Respectfully submitted,

W. E. FOHL, *Chairman,*
F. L. SWANBERG,
J. R. ROBINSON,
Nominating Committee.

On motion, the nominations were closed and the Secretary instructed to cast an unanimous ballot in favor of the officers named, and they were thereupon declared elected.

In the absence of the new Chairman and Vice Chairman, Mr. Fohl then took the chair, and no further business coming before the meeting, the address of the retiring Chairman was presented by Mr. N. F. Hopkins, Civil and Mining Engineer, Harrop & Hopkins, Pittsburgh, on "Economies of Coal Mining."

The ensuing discussion was participated in by: Graham Bright, Cons. Engr., Howard N. Eavenson & Associates; C. H. Dodge, Engr., H. C. Frick Coke Co., Scottdale, Pa.; W. E. Fohl, Cons. Min. Engr.; W. W. MacFarren, Cons. Mech. Engr.; Edward Steidle, Secy., Mining & Metallurgical Advisory Boards, Carnegie Institute of Technology; W. A. Weldin, Blum, Weldin & Co.; and the author.

On motion, duly seconded, the meeting adjourned at 9:10 P. M.

K. F. TRESCHOW, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Tuesday, February 15, at 4:10 P. M., President George T. Ladd presiding, Messrs. Hunter, Affelder, Fohl, Covell, Forsberg, Bayne and the Secretary being present.

The minutes of the last meeting, held January 17, were approved without reading.

Applications from the following having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Billheimer, C. R.	Lewis, Essington
Caffall, Geoffrey Arthur	Olson, Harold Marinius
Dake, Virgil Hungerford	Robertson, David
Desch, John Leo	Young, Lewis E.

ASSOCIATE MEMBERS

Bradshaw, William Daniel	Provan, John Stevenson
McKown, Howard Purcell	Todd, C. L.

JUNIOR

Burgess, Henry Russell

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades is as follows:

MEMBERS

Buerger, Charles B.	Katz, S. H.
Ebberts, A. R.	Legg, Buell Bruce
Johnanson, Hjalmar Konrad	Morse, George H.

ASSOCIATE MEMBERS

Beglinger, Richard T.	Denigan, Edward Presland
Buhl, William	Leebov, Nathan
Craig, Thomas Singer	Maher, Thomas Delaney

Monk, Percy Sgelley

ASSOCIATE

Harris, Charles A.

JUNIORS

Archer, Robert Bridgforth	Carlson, Earl C.

Application for reinstatement was received from A. S. Mirick and, after discussion, it was moved and carried that he be reinstated to membership.

Applications for transfer were received from the following gentlemen and, after discussion, they were transferred to full membership: R. V. Bingay, J. P. Hacking, H. H. Rudd, H. M. Walker.

Letters of resignation were received from the following and were ordered accepted: C. J. Rodman, H. T. Shelley.

The Secretary reported the death of the following members:

George Matheson	Joined Sept., 1924	Died Dec. 30, 1926
A. G. Shaw	Joined April, 1921	Died Jan. 30, 1927

The report of the Secretary, having been audited by the Finance Committee, showing the financial condition of the Society at the close of business January 31, was approved.

The Secretary reported, on behalf of the Entertainment Committee, a most successful Annual Dinner, and stated that a detailed report of the

expenditures and rceipts showed a net profit on the dinner of about $200. The committee reported that they were arranging for our second Annual Open House and Ladies' Night, to be held February 21.

Mr. Hunter, Chairman of the Finance Committee, reported that Mr. Taylor Allderdice, Mr. Graham Bright and Mr. N. F. Brown have been appointed to serve on his committee during the coming year and that the committee wished to submit the following budget for expenditures and receipts for the year 1927. The only item in this budget which was recommended changed was, first, reduction from $1,500 to $1,300 of the Entertainment Committee allotment. Mr. Hunter stated that this reduction had been made after consulting the Secretary, who stated that the committee would be agreeable to this reduction, inasmuch as they had already planned to eliminate one of the activities which they carried on last year, which was found to be not of sufficient interest to be continued this year, viz., our Golf Tournaments. These were conducted last year at an approximate loss of about $300 and, as only a limited number of our members took advantage of them, it was felt we had better cut them down to at least one during the coming year. The committee also recommended including in this year's budget the amount of $500 to cover depreciation on furniture and fixtures. It was recommended that this amount be set, as our auditor this year included between $500 and $600 for depreciation. Second, the item to be changed is that of salary. The committee recommended that Mr. Snyder's salary be increased $10 per month.

ESTIMATED EXPENDITURES

Rent	$ 6,600.00
Salaries	8,640.00
Year Book	650.00
Miscellaneous Printing	1,600.00
Postage	1,100.00
Office and Miscellaneous	1,500.00
Entertainment Committee	1,300.00
Reporting	525.00
Auditing	225.00
Society Pins	150.00
	$22,170.00

ESTIMATED RECEIPTS

Membership	$22,406.00
Sale of PROCEEDINGS	700.00
Interest	1,100.00
Society Pins	150.00
	$24,356.00

Estimated Receipts PROCEEDINGS	$ 6,000.00
Estimated Expenditures PROCEEDINGS	5,950.00

After a general discussion it was moved and carried that the budget of the committee as outlined be approved.

Mr. Covell, Chairman of the House Committee, reported an evening attendance of 326 for the month of January.

Mr. Affelder, Chairman of the Membership Committee, reported one meeting held during the month, at which the regular routine business of the committee was done, and applications received since the last meeting were assigned to the various grades of membership.

The Secretary retired from the room while the election of Secretary took place, and K. F. Treschow was re-elected as Secretary for 1927.

In accordance with action taken at the last meeting of the Board of Direction, the Secretary reported that the communication from the Cleveland Engineering Society regarding an exchange of membership had been presented to the Membership Committee and, after a general discussion, they had unanimously decided to recommend to the Board of Direction that our By-Laws be amended so as to permit an exchange of memberships with the Cleveland Society on the basis suggested in their letter, as they felt this would be of material assistance to both organizations.

After a general discussion, it was moved and carried that the report be received and that the Board adopt the recommendation of the committee and a special committee be appointed, composed of the Chairman of the Membership Committee, the President and the Secretary, to draw up an amendment to be transmitted to the Society by letter ballot. It was suggested that the paragraph quoted from the Constitution of the Cleveland Engineering Society might be used with some minor changes.

Mr. Hunter reported that, at the request of Mr. Ladd, he had attended a meeting called by Chancellor Bowman, of the University of Pittsburgh, to discuss the formation of an industrial museum, a movement which was started by Dr. Stewart, former director, and a committee of this Society, of which Max Hecht was Chairman. Mr. Hunter's detailed report was as follows:

"Attended the luncheon at the University Club, to discuss the formation of an industrial museum. Nineteen persons were present, among whom were Chancellor Bowman, Dr. Samuel Church, Dr. Baker, Dean Mott, S. B. Ely, James O. Handy, Dean Manley, Dean Bishop, Mr. Kaufman and Mr. Aber.

"After luncheon Chancellor Bowman made some brief introductory remarks and introduced Mr. Aber, who spoke at some length on the desirability and field which would be covered by an industrial museum. Brief remarks were made by Dr. Church, Dr. Baker and Mr. Kaufman. All agreed that such a museum could and should be formed.

"Mr. Handy told briefly of the work of the committee of the American Chemical Society, which committee was headed by Mr. Hecht, and who is also head of the committee of the Engineers' Society of Western Pennsylvania. It was a general understanding that if such a museum is formed it should be connected with the Carnegie Institute. No decided action was taken other than the general discussion as outlined."

The Secretary presented a bill which he received in the mail regarding the establishment of a Building and Sanitary Code regulating the design, construction, repair, alteration and maintenance of buildings, and to provide for and formulate and adopt regulations by the Board of Building Standards and the State Department of Health. It was moved and carried that the Secretary communicate with Mr. Danforth as to whether he feels the Society should take any action in connection with this bill.

Mr. Ladd announced the appointment of the following Chairmen of committees: V. R. Covell, House Committee; L. C. Edgar, Publication Committee.

The meeting adjourned at 5:30 P .M.

K. F. Treschow, *Secretary.*

ANNUAL MEETING—MECHANICAL SECTION

The annual meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, February 1, at 8:20 P. M., Chairman William Shaw presiding, 62 members and visitors being present.

The minutes of the last annual meeting, held February 2, were read and approved.

The annual report of the Chairman was read by the Secretary.

The report of the Nominating Committee was read by W. B. Skinkle, Chairman, as follows:

> *To Members and Officers of Mechanical Section:*
>
> DEAR SIRS—Your Nominating Committee appointed to nominate officers for the Section for the ensuing year met today and nominated the following:
>
> J. S. Fulton .... Chairman
> G. E. Dignan .... Vice-Chairman
> C. A. Carpenter
> W. P. Chandler
> T. E. Purcell
> H. G. McIlvried
> H. M. Leathers .... Directors

On motion, the nominations were closed and the Secretary instructed to cast a unanimous ballot in favor of the officers named, and they were thereupon declared elected.

In the absence of the Chairman and Vice-Chairman-elect, C. A. Carpenter took the chair. No further business coming before the Section, the address of the retiring Chairman was presented by William Shaw, Power engineer, Mechanical Division, Bureau of Water, City of Pittsburgh, on "Engineering Analysis Applied to Municipal Water Works."

The ensuing discussion was participated in by: E. E. Bankson, Member of Firm, The J. N. Chester Engineers; C. A. Carpenter, Carpenter & Byrne; N. B. Jacobs, Treas, Morris Knowles, Inc.; J. F. Laboon, Member of Firm, The J. N. Chester Engineers; E. G. Lang, Director, Dept. of Public Works, City of Pittsburgh; Gilbert S. Walker, Consulting Engineer, Pittsburgh; P. S. Wickerham, Consulting Civil Engineer, Butler, Pa.; E. E. Lanpher, Div. Supt., Bureau of Water, City of Pittsburgh; and the author.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. Shaw for his very interesting paper.

The meeting adjourned at 10:30 P. M.

K. F. TRESCHOW, *Secretary.*

JOINT MEETING—ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA (ELECTRICAL SECTION) AND AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS (PITTSBURGH SECTION)

The regular monthly meeting of the Electrical Section of the Engineers' Society of Western Pennsylvania was held jointly with the American Institute of Electrical Engineers, Pittsburgh Section, on Tuesday evening, February 8, at 8 o'clock, D. M. Simons presiding, 480 members and visitors being present.

The reading of the minutes of the last meeting, held January 11, were approved without reading.

No further business coming before the Section, Dexter P. Cooper, of Dexter P. Cooper, Inc., Eastport, Me., addressed the meeting on "The Quoddy Tidal Power Project."

The meeting adjourned at 10 P. M.

K. F. TRESCHOW, *Secretary.*

REGULAR MONTHLY MEETING

The four hundred and forty-fourth regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, February 15, at 8:20 P. M., President George T. Ladd presiding, 37 members and visitors being present.

The minutes of the last regular meeting, held December 14, were read and approved.

The Board of Direction reported the election of eight applicants to the grade of Member, four to the grade of Associate Member and one to the grade of Junior, and the receipt of 16 applications for membership. There was one reinstatement; transfer to higher grade of two members; two resignations accepted, and two deaths reported.

No further business coming before the Society, the paper of the evening was presented, on "Electric Typewriters," by Russell G. Thompson, North East Electric Company, Rochester, N. Y.

A general discussion followed the presentation of the paper.

On motion, a vote of thanks was extended to Mr. Thompson for his very interesting paper.

The meeting adjourned at 10:10 P. M.

K. F. Treschow, *Secretary.*

ILLUMINATING SECTION

The regular meeting of the Illuminating Engineers' Section was held jointly with the Pittsburgh Chapter, Illuminating Engineering Society, in the French Room, William Penn Hotel, Monday, February 21, at 8:15 P. M., Chairman H. L. Johnston presiding, 16 members and visitors being present.

The minutes of the last meeting, held December 13, were read and approved.

No meetings were held in January. A course of six lectures on "Lighting Practice," at Carnegie Institute of Technology in the month of January, constituted the activities of the Section for that month and the chief activities for the year. These lectures were sponsored jointly by the Carnegie Institute of Technology, the Electric League of Pittsburgh and the Illuminating Engineers' Section. A total attendance of approximately 825 seems to indicate that Pittsburgh is interested in the subject of improving lighting conditions generally.

There being no further business, the speaker of the evening was introduced by the Chairman. R. E. Carlson, Edison Lamp Works, General Electric Company, Harrison, N. J., gave a very interesting lecture and demonstration on the construction, operation and regulation of automotive headlights. Mr. Carlson's lecture was based upon his extensive investigation for the Bureau of Standards of the entire subject of automotive headlight equipment.

A general discussion followed Mr. Carlson's paper.

A motion was made, seconded and carried unanimously, endorsing the *Chronicle Telegraph* Safe-Driving Week, and calling to the attention of the *Chronicle Telegraph* the importance of properly adjusted automobile headlights for the safety of night driving.

A rising vote of thanks was extended to Mr. Carlson.

On motion, the meeting adjourned at 9:30 P. M.

K. F. Treschow, *Secretary.*

ANNUAL MEETING—STEEL WORKS SECTION

The annual meeting of the Steel Works Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Wednesday, February 23, at 8:20 P. M., Chairman A. C. Fieldner presiding, 28 members and visitors being present.

The minutes of the last annual meeting were read and approved.

The annual report of the Chairman was read by the Secretary.

The report of the Nominating Committee was presented by Mr. Flanagan as follows:

> *To Officers and Members of Steel Works Section:*
>
> DEAR SIRS—Your Nominating Committee appointed to nominate officers for the Section for the ensuing year met today and appointed the following:
>
> T. J. McLoughlin..........Chairman
>
> W. B. Skinkle..........Vice-Chairman
>
> Louis Ellman
C. M. Johnson
D. D. Pendleton
B. R. Shover
S. S. Wales } ....Directors
>
> Respectfully submitted,
>
> W. P. CHANDLER, JR., *Chairman;*
RALPH OVERTON,
W. M. FLANAGAN,
Nominating Committee.

On motion, duly seconded and carried, nominations were closed and the Secretary was instructed to cast a unanimous ballot for the officers named, who were thereupon declared elected.

No further business coming before the Section, the meeting was called to order by C. M. Johnson, Director, in the absence of the Chairman and Vice-Chairman.

The address of the retiring Chairman was presented by A. C. Fieldner, Superintendent, Pittsburgh Experiment Station, United States Bureau of Mines, Pittsburgh, Pa., on "Co-Operative Research in Ferrous Metallurgy and the Problem of Inclusions in Steel."

Written discussion was presented by: A. C. Field, Engr., Central Alloy Steel Corp., Canton, O.; C. F. W. Rys, Metallurgical Engr., Carnegie Steel Company; James O. Handy, Director, Chemical and Metallurgical Laboratory, Pittsburgh Testing Laboratory; T. D. Lynch, Mgr., M. & P. Engineering Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

The ensuing discussion was participated in by: James Aston, Head, Dept. of Metallurgy & Mining, Carnegie Inst. of Technology; C. H. Herty, Jr., Physical Chemist, U. S. Bureau of Mines; C. M. Johnson, Director, Research & Metallurgical Depts., Park Works, Crucible Steel Co. of America; H. E. Slocum, Chief Chemist, Jones & Laughlin Steel Corp; and the author.

On motion, duly seconded and carried a vote of thanks was extended to Mr. Fieldner for his very interesting and valuable paper.

The meeting adjourned at 10:28 P. M.

K. F. TRESCHOW, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Tuesday, March 15, at 4:10 P. M., Vice President John A. Hunter presiding, Messrs. Clifford, Affelder, Covell, Edgar, Spellmire, Fohl, Forsberg, Fulton, McLoughlin, Lesher and the Secretary being present, those absent being Messrs. Ladd, Chester, Stucki, Fieldner, Eavenson, Bayne and Goodwin.

The minutes of the last regular meeting, held February 15, were approved without reading.

Applications from the following having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Buerger, Charles B. | Katz, S. H.
Ebberts, A. R. | Legg, Buell Bruce
Johanson, Hjalmar Konrad | Morse, George H.

ASSOCIATE MEMBERS

Beglinger, Richard T. | Craig, Thomas Singer
Buhl, William | Denigan, Edward Presland
Maher, Thomas Delaney

ASSOCIATE

Harris, Charles A.

JUNIORS

Archer, Robert Bridgforth | Carlson, Earl C.
Leebov, Nathan

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades is as follows:

MEMBERS

Aichberger, Carl | Blesch, Charles August
Bayntun, Robert L. | Kelley, A. B.
Leichliter, Otto Gay

ASSOCIATE MEMBERS

McLean, Harold Alfred | Passmore, Henry E.
Nelms, George Charles | Todd, Donald Cameron
Pacy, Ernest Harold | White, John C.

JUNIORS

Burgham, Maurice L. | Kinter, Dean Wolf
Verner, James

The Secretary reported the deaths of the following:

C. M. Brown	Joined Sept., 1924	Died Mar. 9, 1927
J. H. Carlin	Joined Nov., 1900	Died Mar. 10, 1927
W. S. Gibson	Joined Sept., 1904	Died Feb. 2, 1927
W. H. Hays	Joined Oct., 1892	Died Nov. 15, 1926

The report of the Secretary showing the financial condition of the Society, having been audited by the Finance Committee, was approved.

The Entertainment Committee reported that arrangements were completed for the second Ladies' Night party to be held Friday, April 22, and a Golf Tournament during September. The Committee has held its organiza-

tion meeting and has been divided into sub-committees, each of which will handle a particular branch of the Entertainment Committee work.

Arrangements are also under way for one or two inspection trips, announcements of which will be made later.

Mr. Covell, Chairman of the House Committee, reported that the Secretary had called his attention to the need in our office of an adding machine and a new chair. Mr. Covell stated that while he had not had a meeting of the Committee, he wished to approve the purchase of these two articles, which would cost respectively $100 and $20, subject to the approval of the Finance Committee, who, he understands, has been consulted on this purchase. Mr. Hunter stated that, as Chairman of the Finance Committee, he would approve this purchase.

It was moved and carried that the Secretary be authorized to purchase the adding machine at a price of $100 and the chair at a price of $20.

Mr. Covell also reported an evening attendance of 462 for the month of February.

Mr. Affelder, Chairman of the Membership Committee, stated that one meeting of the Committee had been held to transact the regular business of the Committee.

On motion, the meeting adjourned at 4:50 P. M.

K. F. TRESCHOW, *Secretary.*

CIVIL SECTION

The regular bi-monthly meeting of the Civil Section of the Engineers' Society of Western Pennsylvania was held in the Reception Room, William Penn Hotel, Tuesday, March 1, at 8:17 P. M., Chairman R. P. Forsberg presiding, 72 members and visitors being present.

The minutes of the last meeting, held November 4, were read and approved.

No other business coming before the Section, the report of the Concrete Committee was presented on "Tentative Specifications for Concrete with Local Aggregates," by Mr. C. S. Davis, Chairman of the Committee, as follows:

"Concrete for structural members shall be made in accordance with the following specifications:

"The proportions of cement, water and aggregate shall be such as to produce concrete that can be worked readily into the corners and angles of the forms and around the reinforcing steel without excessive puddling, without segregation of materials and without accumulation of water or laitance on the surface.

"Concrete shall be classified by its compressive strength as determined from test samples, taken when ready to place and tested when 28 days old. It is recommended that the amount of water in the mix be made as little as practicable in order to secure a mix of the desired workability, but in no case shall the amount of water per bag of cement, including that contained in the aggregate, exceed the amounts given in the following schedule. Moisture absorbed by the aggregates may be subtracted from the amount to be deducted for water contained in the aggregate. The relative proportions, by field volume of cement, fine and coarse aggregate, recommended for the various grades of concrete are also given in the schedule:

3000 lbs. concrete	6.0 gallons	1	1½	2½
2500 lbs. concrete	6.7 gallons	1	2	3
2000 lbs. concrete	7.5 gallons	1	2½	3½
1500 lbs. concrete	8.5 gallons	1	3	4

"If the inundated sand is used, the volume of sand shall be reduced 20 per cent. When aggregate is proportioned by weight, the units of weight shall be based on the field columetric proportions of these specifications.

"Three thousand pounds of concrete is suitable for pressure pipes and tanks and structures exposed to unusual conditions.

"Twenty-five hundred pounds of concrete is suitable for bridges, piers, walls, reinforced columns, beams, slabs and thin walls exposed to outside climatic conditions, and copings, projections, water-tables and horizontal surfaces on which water is likely to accumulate when exposed to outside climatic conditions.

"Two thousand pounds of concrete is suitable for massive walls and similar structures and for reinforced columns, beams, slabs and thin walls not exposed to outside climatic conditions.

"Fifteen hundred pounds of concrete is suitable for foundations not exposed to outside climatic conditions.

"Moisture in the aggregate shall be measured by a method satisfactory to the engineer which will give results within one pound for each 100 pounds of aggregate. All cement shall be Portland cement and shall conform to the Standard Specifications and Tests for Portland Cement of the American Society for Testing Materials—Serial Designation C 9-26.

"All aggregates shall be in accordance with the specifications for local aggregates for concrete adopted January 5, 1926. All water used shall be clean and free from injurious amounts of acids, alkalies, organic or other deleterious materials.

"All concrete shall be thoroughly mixed in a batch mixer of a type approved by the engineer. The mixer shall be equipped with a charging hopper and a water-measuring device. Each batch shall be mixed for at least 1½ minutes after all materials are in the mixer.

"Concrete shall be deposited in the forms as nearly as practicable in its final position in order to avoid rehandling. Spouting from a central plant to the place of depositing shall not be permitted. After having been deposited it shall be puddled until the forms are completely filled, all voids eliminated and all reinforcing steel and other embedded fixtures thoroughly incorporated in the mass.

"Concrete shall be deposited continuously and as rapidly as practicable until the unit of operation, approved by the engineer, is completed.

"Concrete when deposited shall have a temperature of not less than 50 nor more than 90 degrees Fahrenheit. In freezing weather suitable means shall be provided for maintaining its temperature of 50 degrees Fahrenheit for 72 hours or more after placing and until the concrete has thoroughly hardened. Metheds of heating the materials and protecting the concrete shall be subject to the approval of the engineer. Salt, chemicals or other foreign materials shall not be mixed with concrete for the purpose of preventing freezing.

"Exposed surfaces of concrete shall be protected from drying for a period of at least seven days after being deposited.

"Frequent tests may be made by the engineer throughout the work to determine the quality of the concrete. These tests shall be made at the expense of the owner and, in general, shall be made in 8x12-inch cylinders and tested when 7 and 28 days old, in accordance with the Standard Method of Making and Storing Specimens of Concrete in the Field of the American Society for Testing Materials—Serial Designation C 31-21."

Chairman V. R. Covell: "You have heard the report of our Concrete Committee. What disposition shall be made of it?"

It was regularly moved and carried that, in order to get the report before the meeting formally, it be adopted. The Chairman suggested that

the report now be taken up by paragraph and called for discussion on the first paragraph.

It was moved and carried that paragraph No. 1 be adopted as read.

Paragraph 2 was then discussed. After discussion, it was approved as read.

Paragraph 3. Approved as read.

Paragraph 4. Approved as read.

Paragraph which included concrete of 3000, 2500, 2000 and 1500 pounds was approved.

Paragraph 6. It was moved and carried that this paragraph be divided into two paragraphs, beginning with the words "All cement." Unanimously approved.

Paragraph 7. It was moved and carried that this paragraph be divided, the second starting with the words "All water used." Unanimously carried.

Paragraph 8. Approved as read.

Paragraph 9. Approved as read.

Paragraph 10. Approved as read.

Paragraph 11. Approved as read.

Paragraph 12. It was moved and carried that paragraph 12 be amended to read at least four days, rather than seven days as read.

Pragraph 13. Attention was called to the fact that in this paragraph there was a misprint in the third line, which should read—shall be made of 6x12-inch cylinders, instead of 8 as read. Unanimously adopted.

The Chairman then asked the wishes of the meeting in regard to the final disposition of the report, and it was regularly moved and carried that the report be published to the Society, with a letter of transmittal from the Committee, asking for further suggestions and criticisms to be submitted to them on or before April 1, after which the Committee would meet and consider the recommendations and present the report in its final form for adoption by the Society at a later meeting of the Section.

The ensuing discussion was participated in by: Edward Godfrey, Struct. Engr., Robert W. Hunt Co.; V. R. Covell, Chf. Engr., Bureau of Bridges, Dept. Public Works, Allegheny County; P. W. Price, Asst. Engr., Bureau of Bridges, Dept. Public Works, Allegheny County; P. J. Freeman, Chf. Engr., Tests & Specifications, Allegheny County; T. P. Watson, Asst. Engr., Chief Engineer's Dept., Pennsylvania R. R.; C. G. Dunnells, Head, Dept. Building Construction, Carnegie Institute of Technology; J. A Fulkner, Engr., Morris Knowles, Inc.; R. S. Taggart, Dist. Engr., Portland Cement Association; J. J. Croak, Div. Engr., Division of Design, Bureau of Engineering, City of Pittsburgh; F. M. McCullough, Professor, Civil Engineering, Carnegie Institute of Technology; W. H. Smyers, Inspector and Chemist, Duquesne Slag Products Co.; A. W. Dann, V. P. & Treas., Keystone Sand & Supply Co.; A. D. Keagy, Asst. Treas., Pitt Construction Co.; and the author.

On motion, the meeting adjourned at 9:50 P M.

K. F. Treschow, *Secretary.*

ELECTRICAL SECTION

The regular monthly meeting of the Electrical Section of the Engineers' Society of Western Pennsylvania was held jointly with the Pittsburgh Section of the American Institute of Electrical Engineers in the Chamber of Commerce Auditorium, Tuesday, March 8, at 8 P. M., Chairman George S. Humphrey presiding, 325 members and visitors being present.

The minutes of the last regular meeting, held February 8, were read and approved.

No further business coming before the Section, the paper of the evening, on "Power System Stability—a Mechanical Analogue," was presented by Mr. C. L. Fortescue, Manager of Power Transmission and Insular Department, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

A general discussion followed the presentation of the paper.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. Fortescue for his very interesting paper.

On motion, the meeting adjourned at 10:15 P. M.

K. F. Treschow, *Secretary.*

ILLUMINATING ENGINEERS' SECTON

The regular meeting of the Illuminating Engineers' Section of the Engineers' Society of Western Pennsylvania was held jointly with the Pittsburgh Chapter of the Illuminating Engineering Society in the Blue Room, William Penn Hotel, Friday evening, March 11, at 8:15 P. M., Chairman H. L. Johnston presiding, 105 members and visitors being present.

The minutes of the last meeting, held February 21, were approved without reading.

No further business coming before the Section, the paper of the evening, on "Natural Lighting," was presented by Professor H. H. Higbie, University of Michigan, Ann Arbor, Mich., and W. C. Randall, Chief Engineer, Detroit Steel Products Company, Detroit, Mich.

The ensuing discussion was participated in by: George W. Thomas, Chief Engr., H. H. Robertson Co.; George H. Mayer, Gen. Sales Agent, American Window Glass Co.; John A Hoeveler, Mgr., Engineering Dept., Pittsburgh Reflector Co.; Emil Hallgren, Designing Engr., Blaw-Knox Co.; and the authors.

On motion, duly seconded and carried, a vote of thanks was extended to the authors of the paper on their very interesting address.

The meeting adjourned at 10:15 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING

The four hundred and forty-fifth regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday evening, March 15, at 8:08 P. M., President George T. Ladd presiding, 183 members and visitors being present.

The minutes of the last meeting, held February 15, were read and approved.

The Board of Direction reported the election of six applicants to the grade of Member, seven to the grade of Associate Member, one to the grade of Associate and two to the grade of Junior; the receipt of 13 applications for membership; two resignations accepted; and four deaths reported.

No further business coming before the Society, the paper of the evening, on "The Rational Design of Steel Structures for Arc Welding," was presented by Messers. Gilbert D. Fish, Consulting Structural Engineer, Westinghouse Electric & Manufacturing Company, New York City, and A. M. Candy, Engineer, Arc Welding Engineering Department, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

The ensuing discussion was participated in by: C. S. Davis, Consulting Engr., private practice; Samuel E. Duff, Consulting Engr., Pittsburgh; S. L. Goodale, Professor Metallurgy, University of Pittsburgh; Emil Hallgren,

Designing Engr., Blaw-Knox Co.; R. A. Mathers, Engr., Erection Dept., American Bridge Co.; W. I. Parry, Engr., Salesman, Carnegie Steel Co.

It was moved and carried unanimously that a committee be appointed to formulate and recommend to the Building Department of the city changes in the code which will permit welding to as great an extent as possible.

On motion, a vote of thanks was extended to the authors of the paper for their very interesting and instructive paper.

The meeting adjourned at 10:45 P. M.

K. F. Treschow, *Secretary.*

ELECTRICAL SECTION

The annual meeting of the Electrical Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday evening, March 22, at 8:15 o'clock, Chairman George S. Humphrey presiding, 132 members and visitors being present.

The minutes of the last annual meeting, held March 31, were read and approved.

The annual report of the Chairman was read by the Secretary.

The report of the Nominating Committee was read by the Secretary, as follows:

To Officers and Members of the Electrical Section:

Dear Sirs—Your Nominating Committee met February 1 in the Society Rooms at 2:30 and nominated the following officers for the ensuing year:

W. C. Goodwin .... Chairman

A. Pinkerton .... Vice-Chairman

J. I. Alexander
Paul Caldwell
H. E. Dyche
D. M. Simons
R. E. Uptegraff } .... Directors

Respectfully submitted,

G. E. Stoltz, *Chairman,*
R. L. Kirk,
J. M. Miller,
Nominating Committee.

On motion, the nominations were closed and the Secretary requested to cast a unanimous ballot, and the nominees were thereupon declared elected.

Due to the absence of the new Chairman, Vice-Chairman A. Pinkerton then took the chair.

No further business coming before the Section, the paper of the evening, the retiring Chairman's adress, was presented by Mr. George S. Humphrey, Electrical Engineer, West Penn Power System, Pittsburgh, on "The Chicago-Boston Interconnected Transmission Systems."

The ensuing discussion was participated in by: M. R. Scharff, Chief Engr., Philadelphia Co.; G. Sutherland, Elec. Engr., Byllesby Engrg. & Management Corp.; T. J. Williams, Supt. Operation, Ohio Power Co., Canton, O.

On motion, a vote of thanks was given Mr. Humphrey for his interesting paper and for the good work as Chairman of the Section.

The meeting adjourned at 9:45 P. M.

K. F. Treschow, *Secretary.*

MINING SECTION

The regular bi-monthly meeting of the Mining Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, March 29, at 8:25 P. M., Vice-Chairman L. O. Lougee presiding in the absence of the Chairman, 21 members and visitors being present.

The minutes of the last meeting, held January 25, were read and approved.

No further business coming before the Section, the paper of the evening, on "Face Preparation for Blasting," was presented by Mr. B. L. Lubelsky, Explosives Engineer, Pittsburgh Coal Company, Pittsburgh, Pa.

The ensuing discussion was participated in by: N. A. Tolch, Research Fellow of Mining, Carnegie Institute of Technology; and the author.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. Lubelsky for his very excellent and instructive paper.

No further business coming before the Section, the meeting adjourned at 9 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Tuesday, April 19, at 4:20 P. M., President George T. Ladd presiding, Messrs. Hunter, Forsberg, Fulton, Bayne, Johnston, Covell, Affelder and the Secretary being present, Messrs Stucki, Clifford, Eavenson, Edgar, Spellmire, Fohl, McLoughlin, Goodwin, Fieldner, Lesher and Chester unable to attend.

The minutes of the last meeting, held March 15, were approved without reading.

Applications from the following gentlemen having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Aichberger, Carl	Baynton, R. S.
Blesch, Charles August	Leichliter, Otto Gay
Kelley, A. B.	

ASSOCIATE MEMBERS

McLean, Harold Alfred	Passmore, Henry E.
Nelms, George Charles	Todd, Donald Cameron
Pacy, Ernest Harold	White, John C.

JUNIORS

Burgham, Maurice L.	Kinter, Dean Wolf
Verner, James	

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Baker, John Marion	Cooper, Leroy Warrick
Blair, George Sheppard	Lose, James E.
Bonsall, Judson	Loomis, F. W.
Saeger, Geoffrey Aaron	

ASSOCIATE MEMBERS

Peters, Frank Grant	Thomas, Roger F.

STUDENT JUNIOR

Knoble, Edward Fred

Application was received from Mr. D. W. Blakeslee for reinstatement and, after discussion, the Secretary was requested to advise him of his reinstatement to membership.

Applications for transfer to higher grade were received from the following and, after discussion, they were transferred to the grade of Member:

Monk, Percey Shelley	Uptegraff, Roy Ernest

The Secretary reported the death of the following members:

J. W. Furlow..........	Joined Jan., 1927	Died Mar. 4, 1927
A. M. Lynn............	Joined Mar., 1924	Died Apr. 8, 1927

The report of the Secretary showing the financial condition of the Society at the close of business March 31, having been audited by the Finance Committee, was approved.

The Secretary reported, on behalf of the Entertainment Committee, that a most successful Ladies' Night party had been held Monday evening, and

that the committee had planned one or two social activities for the summer months, together with one or more inspection trips.

Mr. Covell, chairman of the House Committee, reported that Mr. Butler, of the William Penn Hotel, had been in touch with the Secretary in connection with possible change of quarters and that he intended to have a conference with Mr. Butler and the Secretary within the next week or ten days. He also reported an evening attendance of 556 for the month of March.

The Membership Committee held one meeting to go over applications received since the last meeting of the Board and assigning them to the various grades of membership and to act on any resignations, etc., received.

The Secretary read a letter from Mr. Gilbert D. Fish, Consulting Structural Engineer of the Westinghouse Electric & Manufacturing Company, asking that this Society co-operate in drawing up a set of specifications on structural welding. Mr. Fish stated that their company had been called upon many times for a printed set of specifications and design data and felt that, inasmuch as our Society was interested in this subject, we should co-operate with them in making such specifications. After a general discussion it was moved and carried that the Secretary write Mr. Fish stating that it was the feeling of the Board of Direction that such specifications should be drawn up by one of the national bodies, either the American Welding Society or the American Society for Testing Materials, as such specifications should be of national scope rather than a local one.

The President called attention to action taken at the March 15 meeting of the Society whereby it was unanimously voted to authorize him to appoint a special committee of five to serve as a committee of this Society to endeavor to have the Building Code of the City of Pittsburgh changed so as to permit structural welding. Mr. Ladd stated that he had not appointed this committee, as he wished for advice and assistance of the Board in making this appointment. After a general discussion the President appointed the following: John A. Hunter, chairman; W. L. Affelder, J. S. Fulton, R. P. Forsberg and V. R. Covell.

The Secretary presented a letter from Pennsylvania State College asking us to appoint delegates to represent the Society in the election of trustees to be held Saturday, June 11. Mr. Affelder stated that he would get in touch with the Secretary and suggest names of men who could be appointed for this work.

Mr. Covell presented the following resolution and, after a general discussion, it was moved and carried that the President be authorized to appoint a special committee of three to co-operate with other similar committees. The following committee was appointed: W. E. Fohl, chairman; W. B. Spellmire and George H. Neilson.

"Whereas, The Legislature of the Commonwealth of Pennsylvania has enacted the Engineers' Licensing Law; and

"Whereas, It is expected that the Governor will sign the law, thus making it effective; and

"Whereas, It is a duty incumbent upon the Governor under the terms of the Act to appoint a new Board for Registration;

"Whereas, There was considerable disappointment on the part of engineers of Western Pennsylvania as to the administration of the former Act, which was declared unconstitutional; and

"Whereas, Engineers are in the best position to judge of the qualifications of the members of such Board;

"Be It Resolved, That the Board of Direction of the Engineers' Society of Western Pennsylvania appoint a committee to act with similar committees

of other groups of engineers similarly inclined, to present a list of names of engineers of the Pittsburgh district to the Governor with the request that the names on this list be given careful consideration in making the appointments."

The meeting adjourned at 5:00 P. M.

K. F. Treschow, *Secretary.*

MECHANICAL SECTION

The regular bi-monthly meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania and the Pittsburgh Section of the American Society of Mechanical Engineers was held jointly Tuesday evening, April 5, at 8:15 o'clock, in the Blue Room of the William Penn Hotel, Chairman T. A. Peebles presiding the first half for the A.S.M.E., and Chairman J. S. Fulton the latter half for the Engineers' Society of Western Pennsylvania, 74 members and visitors being present.

Mr. Peebles opened the meeting with the reading of the minutes of the last joint meeting, after which he called attention to the members of the Pittsburgh Section, A.S.M.E., to a communication received from the Detroit Section, which he asked the Secretary to read. This letter was a request that the Pittsburgh Section endorse Mr. Alexander Dow, President of the Detroit Edison Company, for President of the American Society of Mechanical Engineers. After discussion, it was regularly moved and carried that this Section go on record as endorsing Mr. Dow.

Mr. Peebles then turned the meeting over to Mr. Fulton, who introduced the speaker of the evening, Mr. J. F. Shadgen, Engineer, Smoot Engineering Corporation, New York City, who presented a paper on "Boiler Control and Combustion Efficiency."

The ensuing discussion was participated in by: W. N. Flanagan, Special Engr, Carnegie Steel Co; Wm. Drylie, Supt, Water & Steam Dept, Edgar Thomson Works, Carnegie Steeel Co, Braddock, Pa; W. McK. Stephens, Steam Engr, West Penn Power System, Springdale, Pa; and the author.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. Shadgen for his very interesting paper.

The meeting adjourned at 9:41 P. M.

K. F. Treschow, *Secretary.*

ELECTRICAL SECTION

The regular monthly meeting of the Electrical Section of the Engineers' Society of Western Pennsylvania was held jointly with the Pittsburgh Section of the American Institute of Electrical Engineers, Tuesday evening, April 12, in the Chamber of Commerce Building, at 8:10 o'clock, D. M. Simons, chairman of the Pittsburgh Section of the A.I.E.E., presiding, 375 members and visitors being present.

The minutes of the last regular meeting, held March 22, were approved without reading.

No further business coming before the Section, the paper of the evening, on "Mercury Arc Rectifiers," was presented by F. E. Faron, Electrical Engineer, Railway Engineering Department, General Electric Company, Schenectady, N. Y.

A general discussion followed the presentation of the paper.

On motion, duly seconded and carried, the meeting adjourned at 10:30 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING

The four hundred and forty-sixth regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, April 19, at 8:30 P. M., President George T. Ladd presiding, 12 members and visitors being present.

On motion, the reading of the minutes of the last meeting, held March 15, was dispensed with and were approved without reading.

The Board of Direction reported the election of five applicants to the grade of Member, six to the grade of Associate Member, and three to the grade of Junior, and the receipt of ten applications for membership. There was one reinstatement, two transfers to higher grade, five resignations accepted and two deaths reported.

No further business coming before the Society, the paper of the evening was presented by Joseph White, Engineer in Charge of Statistics and Publicity, Department of Public Works, Allegheny County, on "The Engineer and Publicity."

The meeting adjourned at 9:15 P. M.

K. F. TRESCHOW, *Secretary.*

CIVIL SECTION

The regular bi-monthly meeting of the Civil Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, May 3, at 8:20 P. M., Mr. Laboon acting as Chairman in the absence of the Chairman, 51 members and visitors being present.

The minutes of the last meeting, held March 1, were read and approved.

The final report of the Committee on Specifications for Concrete with Local Aggregates was presented by Mr. C. S. Davis, Chairman. On motion, duly seconded and carried, the specifications as revised were approved and the Secretary was requested to send them out to the membership for approval or rejection by letter ballot.

No further business coming before the Section, the paper of the evening, on "How We Forecast the Weather," was presented by Mr. Wm. S. Brotzman, Meteorologist, Weather Bureau, U. S. Government, Pittsburgh, Pa.

The ensuing discussion was participated in by: V. R. Covell, Chf. Engr, Bureau of Bridges, Dept. Public Work, Allegheny County; G. E. Flanagan, Mech. Engr, Heyl & Patterson, Inc.; J. F. Laboon, Member Firm, J. N. Chester, Engineers; C. A. Sipe, Mfg. Analysist, Westinghouse Elec. & Mfg. Co.; C. S. Davis, Cons. Engineer, Pittsburgh, Pa.; Edward Godfrey, Struct. Engr, Robert W. Hunt Co.; J. B. Keller, Asst. Efficiency Engr, Clairton By-Products Coke Works; Wm. P. Parker, Consulting Structural Engr, Philadelphia, Pa.; R. S. Craig, Struct. Darftsman, Bureau of Bridges, Dept. Public Works, Allegheny County; John A. Graham, Supt. Buildings & Grounds, Shady Side Academy; E. E. Bankson, Member Firm, J. N. Chester, Engineers; W. H. McCune, Chief, Inspection Dept, American Sheet & Tin Plate Co.; and the author.

Mr. Covell stated that it seemed that Mr. Davis had raised an important point which should be looked into and investigated. He stated he had not checked up on the figures that Mr. Davis presented, but felt sure they were correct. He made a motion that a committee of three members be appointed to study the question of wind pressures with a view to ascertaining the adequacy of the present code of Pittsburgh and report at the next meeting of the Section.

Motion was duly seconded and carried that the Chairman appoint such a committee.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. Brotzman for his very interesting address.

The meeting adjourned at 10:10 P. M.

K. F. Treschow, *Secretary.*

ELECTRICAL SECTION

The regular monthly meeting of the Electrical Section of the Engineers' Society of Western Pennsylvania was held jointly with the Pittsburgh Section of the American Institute of Electrical Engineers in the Auditorium of the Chamber of Commerce, Tuesday, May 10, at 8:00 P. M., Mr. D. M. Simons presiding in the first part of the meeting and Mr. K. F. Treschow the latter part of the evening, 375 members and visitors being present.

The report of the Nominating Committee was presented and, no further nominations being made, the following officers were elected:

W. C. Goodwin....................................Chairman
H. E. Dyche..Secretary

J. B. McNeil
L. A. Terven
E. A. Hester
G. Sutherland
C. F. Riker
J. A. Cadwallader
.......Executive Committee

No further business coming before the Section, the meeting was addressed by Mr. F. J. Chesterman, Vice President and General Manager, The Bell Telephone Company of Pennsylvania, on "Development of Executive and Administrative Ability."

After the paper was presented the Chairman announced that the balance of the evening would be given over to a luncheon and entertaiment to be provided by the Entertainment Committee.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Tuesday, May 17, at 4:10 P. M., President George T. Ladd presiding, Messrs. Clifford, Affelder, Spellmire, Fohl, Covell, Forsberg and Johnston being present, and Messrs. Hunter, Chester, Stucki, Eavenson, Edgar, Fieldner, Lesher, Goodwin, Fulton, Bayne and McLoughlin absent.

The minutes of the last regular meeting, held April 19, were approved without reading.

Applications from the following applicants, having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Baker, John Marion
Blair, George Sheppard
Bonsall, Judson
Cooper, Leroy Warrick
Loomis, F. W.
Lose, James E.
Saeger, Geoffrey Aaron

ASSOCIATE MEMBERS

Peters, Frank Grant
Thomas, Roger F.

STUDENT JUNIOR

Knoble, Edward Fred

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Beck, Herman
Hubbard, Fred
Stewart, James Ernest
Tishlarich, Ottmar M.
Simons, E. S.
Watkins, Donald N.
Wiggins, W. D.

ASSOCIATE MEMBERS

Berger, John N.	Hildreth, Harold Francis
Crawbuck, John D.	Menzin, A. L.

Turner, A. S., Jr.

JUNIOR

Higgins, Robert W.

Letters of resignation were received from the following and, after discussion, they were ordered accepted: C. A. Blesch, D. C. Carmichael, J. W. Dalzell, C. L. Rixmann and C. A. Whiteman.

Application for reinstatement was received from D. A. Polhemus, and the Secretary was requested to advise him of his reinstatement to membership.

The report of the Secretary showing the financial condition of the Society at the close of business April 30, having been audited by the Finance Committee, was approved.

Mr. Clifford, Chairman of the Entertainment Committee, reported that the committee plans to hold an inspection trip in conjunction with the Power Meeting to be held in Erie, Pa., on June 3 and 4. An invitation was extended to us by the Technical Federation of Erie to participate in this meeting, and it was felt that this would serve as a substitute for the usual long-distance inspection trip each spring. Announcements of this trip will be mailed within the next few days.

Mr. V. R. Covell, Chairman of the House Committee, reported an evening attendance in the Society rooms of 579 for the month of April.

Mr. Affelder, Chairman of the Membership Committee, reported that one meeting of the committee had been called to go over applications received since the last meeting of the Board and transact other business coming before the committee.

In the absence of Mr. Hunter, the Secretary presented the following report of a special committee appointed at the last meeting of the Board in accordance with instructions received at the regular monthly meeting of the Society in April to investigate the possibility of having the Building Code of the City of Pittsburgh changed to permit structural welding:

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

Your committee appointed at the last meeting of the Board to investigate the possibility of having the Building Code of the City of Pittsburgh changed so as to permit structural welding, has investigated this subject and believes that it is a little too early to attempt to recommend a change in the Code at this time.

The subject of structural welding is yet in its infancy and, as with all new projects, it takes some little time to educate the public, we believe that more can be accomplished if we delay action until more data have been secured and more actual work done in the structural welding field.

Respectfully submitted,

JOHN A. HUNTER, *Chairman.*

After discussion, it was moved and carried that the report of the committee be approved as read.

The Secretary reported that in accordance with instructions received at the last meeting of the Board a letter ballot had been taken on the amendment to our By-Laws, permitting an exchange of membership with other

societies granting us a similar privilege, and the total number of votes cast was 387 in favor of the amendment.

After discussion, it was regularly moved and carried that the Board authorize an exchange of membership with the Cleveland Engineering Society in accordance with their letter, effective January 1, 1927.

The Secretary stated that Mr. Knowles had called him today stating that our Society might well take some action on the appointment by the President of the United States of a Commission to study the flood situation in this country. Mr. Knowles stated that he believed the President realized the importance of a study by prominent engineers in this country and abroad in order to avoid a repetition of the recent disastrous flood in the Mississippi Valley. However, there are no funds available at this time for the use of such a Commission, and if the Commission is to be appointed Congress will have to make an appropriation at its coming session to cover this work. For this reason it was suggested that as many organizations as possible throughout the country write the President asking for the appointment of this Commission in order that he may know the people are backing it, and in order to encourage Congress to make the necessary appropriation.

After a general discussion it was moved and carried that, before this Society takes action, the opinion of the American Engineering Council should be secured, as this is primarily their field, and they have probably gone into the matter and know just what action should be taken. The Secretary was instructed to write the American Engineering Council and report back to the Board at the next meeting.

The meeting adjourned at 5:00 P. M.

K. F. TRESCHOW, *Secretary.*

REGULAR MONTHLY MEETING

The four hundred and forty-seventh regular meeting of the Engineers' Society of Western Pennsylvania was held in the Reception Room, William Penn Hotel, Tuesday, May 17, at 8:15 P. M., Past President W. B. Spellmire presiding, 53 members and visitors being present.

The minutes of the last meeting, held April 19, were read and approved.

The Board of Direction reported the election of seven applicants to the grade of Member, two to the grade of Associate Member and one to the grade of Junior, and the receipt of 13 applications for membership. Five resignations were accepted and there was one reinstatement.

No further business coming before the Society, the paper of the evening was presented by Mr. Louis Wiley, Business Manager, *New York Times*, New York City, on "The Newspaper Industry."

The ensuing discussion was participated in by: H. D. James, Control Engr, Westinghouse Elec. & Mfg. Co.; T. D. Lynch, Mgr, M. & P. Engineering Dept, Westinghouse Elec. & Mfg. Co.; Max Hecht, Chief Chemist, Duquesne Light Co.; G. L. Chirsty, Chf. Engr, Pittsburgh-Des Moines Steel Co.; W. B. Spellmire, Mgr, General Electric Co.; P. S. Whitman, Engr, Riter-Conley Mfg. Co.; and the author.

On motion, duly seconded and carried, a vote of thanks was extended to Mr Wiley for his very interesting address.

The meeting adjourned at 9:10 P. M.

K. F. TRESCHOW, *Secretary.*

BOARD OF DIRECTION

June

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Tuesday, June 14, at 4:10 P. M., President George T. Ladd presiding, Messrs. Hunter, Spellmire, Fohl, Edgar, Forsberg, McLoughlin, Johnston, Covell, Fieldner, Clifford and the Secretary being present.

The minutes of the last meeting, held May 17, were approved without reading.

Applications from the following applicants having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Beck, Herman	Stewart, James Ernest
Hubbard, Fred	Tishlarich, Ottmar M.
Simons, E. S.	Watkins, Donald N.

Wiggins, W. D.

ASSOCIATE MEMBERS

Berger, John N.	Hildreth, Harold Francis
Crawbuck, John D.	Menzin, A. L.

Turner, A. S., Jr.

JUNIOR

Higgins, Robert W.

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Crawford, Robert Monroe	Larson, Walter Emanuel
Kenney, Cyrus Watson	Tower, Elwood S.

JUNIOR

TenEyck, J. C., Jr.

STUDENT JUNIORS

Phillips, Fernley Berrington

Letters of resignation were received from the following and were ordered accepted: G. W. Case, A. L. Menzin and W. C. Stripe.

V. R. Covell, Chairman of the House Committee, reported an evening attendance of 415 for the month of May.

In the absence of the Chairman of the Membership Committee, the Secretary reported for the committee that one meeting had been held to go over applications received since the last meeting and make assignment to the various grades of membership and transact any other business of the committee.

The report of the Secretary showing the financial condition of the Society at the close of business May 31, having been audited by the Finance Committee, was approved.

In accordance with instructions of the Board at the last meeting, the Secretary wrote Mr. Wallace, Executive Secretary of the American Engineering Council, regarding the movement to request the President to appoint a Flood Commission. Mr. Wallace replied that this matter was being considered by the American Engineering Council ant that they and several

other organizations had passed a resolution urging the President to appoint such a commission. Mr. Wallace further suggested that this Society pass a resolution similar to the copy enclosed with his letter and that it be presented to him in order that the Engineering Council might present these resolutions when taking up the matter with the President. They felt that this would be more effective than having each organization sending in resolutions at different times.

After considerable discussion, the following resolution was unanimously passed:

> Resolved, That it is the sense of the Board of Direction of the Engineers' Society of Western Pennsylvania that there be created by the President of the United States a Flood Commission for the purpose of examining into the problem and reporting upon the problem of a comprehensive plan for the control of the Mississippi River and the prevention of a repetition of the disastrous conditions resulting from the recent flood; and be it further
>
> Resolved, That adequate funds be provided for this investigation; and be it further
>
> Resolved, That the said commission shall consist of members of which the majority shall be civilian engineers of national reputation in hydraulics or of experience and training especially qualified for an examination into the report upon the problem of the Mississippi River.

It was further resolved that this resolution be forwarded to Mr. Wallace in accordance with his suggestion.

The Secretary presented the following letter from W. C. Hawley:

President and Board of Direction,
Engineers' Society of Western Pennsylvania.

Dear Sirs:

The Public Service Commission of the State of Pennsylvania has been in existence nearly fourteen years. During that time, for various reasons, there have been on this commission, composed of seven members, about 30 commissioners. Of that number two have been engineers and the great majority have been members of the legal profession. Not more than three or four of the men appointed to membership on the commission have had any practical experience with either the design of construction or operation of public utilities prior to their appointment.

Soon after the election of Governor Pinchot, this matter was called to his attention by the various engineering societies of the state, including our own Society, and he appointed one engineer. At the present time the seven members of the commission are lawyers. It is understood that Chairman W. D. B. Ainey, who has served long and well, will retire in the near future on account of his health. Considering the numerous changes that have taken place in the past, there may be other vacancies and I, therefore, respectfully suggest that the Engineers' Society of Western Pennsylvania communicate with Governor Fisher, calling his attention to this matter and requesting him to give consideration to the appointment of an engineer to the Public Service Commission to fill the next vacancy which occurs. I believe that it will be well to secure the co-operation of the other engineering societies of the state in this matter.

The problems which come before the Public Service Commission

all involve matters of engineering. We have been advised in the past that they do not need an engineer on the commission because "an engineer can be hired if he is needed." As a matter of fact, there should be on the commission—in addition to lawyers—engineers, business men and those familiar with the operation of public utilities. The best attorney appointed to the commission without previous utility experience requires months, or even a year or two, before he becomes so familiar with utilities and their regulation that he is competent to pass judgment on such matters.

This is a matter in which almost every citizen of the State of Pennsylvania is interested, for in these days practically every one receives service from one or more of the public utilities and is benefited by just and reasonable regulation of service and rates.

Yours truly,
W. C. Hawley.

After a general discussion, it was moved and carried that the President and Secretary be authorized to draw up a resolution urging the Governor to appoint one or more engineers on the Public Service Commission of this state, and that copies of this resolution be sent to the various engineering societies in the state with the suggestion that they take similar action.

The Secretary reported that the third Conference of Engineering Societies Secretaries would be held in Cleveland on June 16 and 17 and that this Society had been asked to be represented, and it was moved and carried that the Secretary be instructed to attend this conference at the expense of the Society.

The meeting adjourned at 5:10 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION

September

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Tuesday, September 20, at 4:10 P. M., President George T. Ladd presiding, Messrs. Affelder, Hunter, Covell, Eavenson, Edgar, Spellmire, Forsberg, Fulton and the Secretary being present; Messrs. Chester, Stucki, Clifford, Fieldner, Fohl, Lesher, Goodwin, Bayne, McLoughlin and Johnston being uanble to attend.

The minutes of the last meeting, held June 14, were approved without reading.

Applications from the following applicants having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Crawford, Robert Monroe
Kenney, Cyrus Watson
Larson, Walter Emanuel
Tower, Elwood S.

JUNIOR

TenEyck, J. C.

STUDENT JUNIOR

Phillips, Fernley Berrington

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Anderson, Harry Clifford	Landahl, Eugene Everett
Beers, Harold S.	Martin, George Foster, Jr.
Dunbar, F. B.	Mills, Charles Peale
Dykeman, Howard E.	Moore, R. W. E.
Estep, Thomas G.	Peiffer, Thomas J.
Ewalt, Dwight Sapp	Peth, Herbert William
Holbrook, E. A.	Shotton, Bruce Gillespie
Jones, Charles L.	Tew, John Baker

ASSOCIATE MEMBERS

Danielson, George	Over, Raymond W.
Johnson, Fred McCoy	Richardson, Charles Parker
Lacock, J. S.	Schenck, Rand Gilmore
McKee, W. McC.	Waldschmidt, Howard Conrad

JUNIOR

Van Es, Joseph Henry

Letters of resignation were received from the following and, after discussion, they were ordered accepted: R. Berg, H. F. A. Duensing, W. F. Gillies and M. E. Skinner.

The Secretary reported the death of W. F. Clark, who joined January, 1925, and died February 21, 1927.

The reports of the Secretary showing the financial condition of the Society at the close of business June 30, July 31 and August 31, having been audited by the Finance Committee, were approved.

After discussing the financial statement, it was suggested that the Secretary be requested to place the total accounts receivable on each statement in order that the Board might have an idea of the amount due each month.

The question of changing our investments was brought up for discussion and it was regularly moved and carried that the Chairman of the Finance Committee, together with the President and Treasurer, be authorized to transfer any of the bonds of the Society and purchase new ones as they may feel essential to the improvements of our investments; any changes made to be approved by the Board at a subsequent meeting.

The Secretary reported on behalf of the Entertainment Committee that a very successful golf tournament had been held at the Pittsburgh Field Club with the largest attendance of any tournament yet held.

The committee also held a meeting to consider plans for the Fall and Winter, including the Annual Banquet.

V. R. Covell, Chairman of the House Committee, reported an evening attendance for the months of June, July and August of 910.

A meeting of the Membership Committee was held to assign applications to the various grades of membership, act upon resignations, etc.

The following names were suggested for engraved invitations from the Board to become members of the Society:

Thomas Moses, President, H. C. Frick Coke Company;
W. S. Finlay, President, West Penn Electric Company;
A. H. Beale, President, A. M. Byers Company;
C. A. Fisher, President, Jones & Laughlin Steel Corporation;
Gordon Fisher, President, Spang-Chalfant Company;
J. H. Hillman, President, Hillman Coal & Coke Company.

It was regularly moved and carried that the Secretary be authorized to send these invitations.

The meeting adjourned at 5:25 P. M.

K. F. TRESCHOW, *Secretary.*

ELECTRICAL SECTION

The regular monthly meeting of the Electrical Section of the Engineers' Society of Western Pennsylvania was held jointly with the Pittsburgh Section of the American Institute of Electrical Engineers at the East Pittsburgh Works of the Westinghouse Electric & Manufacturing Company, Secretary H. E. Dyche presiding, 326 members and visitors being present.

There was an inspection trip through the plant to inspect railway electrification equipment in the Railway Aisle, after which dinner was served in the Westinghouse Company Cafeteria. Immediately after dinner, N. W. Storer, Consulting Transportation Engineer of the Westinghouse Company, presented a paper on "Tendencies in Modern Transportation."

On motion, duly seconded and carried, the meeting adjoured at 8:45 P. M.

K. F. TRESCHOW, *Secretary.*

STEEL WORKS SECTION

The regular bi-monthly meeting of the Steel Works Section of the Engineers' Society of Western Pennsylvania was held in the Club Rooms, William Penn Hotel, Tuesday, June 14, at 8:25 P. M., Chairman T. J. McLoughlin presiding, 50 members and visitors being present.

The minutes of the last meeting, held February 23, were read and approved.

No further business coming before the Section, the paper of the evening, on "Economizers for Boilers," was presented by Walter F. Keenan, Chief Engineer, The Power Specialty Company, New York City.

The ensuing discussion was participated in by: R. E. Butler, Sales Agent, Babcock & Wilcox Co.; H. M. Olson, Dist. Mgr, The Permutit Co.; T. J. McLoughlin, Fuel Engr, Carnegie Steel Co., Duquesne, Pa.; R. S. Baynton, Rust Engineering Co.; and the author.

A vote of thanks was extended to Mr. Keenan for his very interesting paper.

On motion, duly seconded and carried, the meeting adjourned at 9:52 P. M.

K. F. TRESCHOW, *Secretary.*

REGULAR MONTHLY MEETING

The four hundred and forty-eighth regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, September 20, at 8:30 P. M., President George T. Ladd presiding, —— members and visitors being present.

The minutes of the last regular meeting, held May 17, were read and approved.

The Board of Direction reported the election of four applicants to the grade of Member; one to the grade of Junior and one to the grade of Student Junior; and the receipt of 25 applications for membership. Four resignations were accepted and one death reported.

There being no further business, the paper of the evening was presented by T. F. Githens, Mechanical Engineer, Cleveland Twist Drill Company, Cleveland, O., on "Methods of Securing Acceptance and Use of Nationally Recognized Standards."

The ensuing discussion was participated in by: George T. Ladd, President, Ladd Water Tube Boiler Co.; John A. Hunter, Asst. Chf. Engr, American Sheet & Tin Plate Co.; and the author.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. Githens for his very interesting paper.

The meeting adjourned at 9:40 P. M.

K. F. TRESCHOW, *Secretary.*

ELECTRICAL SECTION

The regular monthly meeting of the Electrical Section of the Engineers' Society of Western Pennsylvania was held jointly with the Pittsburgh Section of the American Institute of Electrical Engineers in the Chamber of Commerce Auditorium, Tuesday, October 11, at 7:30 P. M., Secretary H. E. Dyche presiding, 430 members and visitors being present.

A motion picture was shown, after which the paper of the evening, on "Television," was presented by Messrs. H. M. Stoller and J. W. Horton, of the Bell Telephone Laboratory.

A vote of thanks was extended to the authors for their very interesting address.

The meeting adjourned at 10:15 P. M.

K. F. TRESCHOW, *Secretary.*

ALL-DAY CONFERENCE

A conference of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held jointly with the Pittsburgh Section of the American Society of Mechanical Engineers in the Blue Room of the William Penn Hotel, Monday, October 17, at 9:30 P. M., R. W. Andrews, Chairman of the Pittsburgh Section, A. S. M. E., presiding, 240 members and visitors being present.

The reading of the minutes of the last meeting, held April 5, were approved without reading.

The following papers were presented: "High-Pressure Boiler Development," by Dr. D. S. Jacobus, Advisory Engineer, Babcock & Wilcox Co., New York City; "High-Pressure Steam Turbines," by G. B. Warren, Engineer, Turbine Engineering Department, General Electric Company, Schenectady, N. Y.; and "Piping, Valves and Fittings for High-Pressure Steam Service," by F. H. Morehead, Chief Engineer, Walworth Company, Boston, Mass.

Written discussion was presented by: Philip G. Darling, Ashcroft Mfg. Co., Bridgeport, Conn.; Sabin Croker, Detroit Edison Co., Detroit, Mich.

The ensuing discussion was participated in by: R. W. Andrews, Andrews-Bradshaw Co.; H. M. Armocoast, Mech. Engr., Superheater Co., New York City; J. B. Crane, Engr., Ladd Water Tube Boiler Co.; H. E. Emmons, Chf. Engr., Republic Iron & Steel Co., Youngstown, O.; T. G. Estep, Assoc. Professor, Mechanical Engineering, Carnegie Inst. of Technology; J. C. Hobbs, Supt. Power, Diamond Alkali Co., Painesville, O.; H. B. Mann, V. P., Dravo-Doyle Co.; E. W. Norris, Engr., Mechanical Div., Stone & Webster, Inc., Boston, Mass.; J. A. Powell, W. S. Barstow Management Assoc., Inc., New York, N. Y.; J. A. Snyder, Chief Inspector, Hartford Steam Boiler Inspection & Insurance Co.; F. M. VanDeventer, Mech. Engr., Construction Dept., H. L. Doherty Co., New York, N. Y.; and the authors.

On motion, duly seconded and carried, the meeting adjourned at 4:37 P. M.

K. F. TRESCHOW, *Secretary.*

REGULAR MONTHLY MEETING

The four hundred and forty-ninth regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, William Penn Hotel, Tuesday, October 18, at 8:20 P. M., Past President W. E. Fohl presiding in the absence of the President, 80 members and visitors being present.

The minutes of the last meeting, held September 20, were approved without reading.

The Board of Direction reported the election of sixteen applicants to the grade of Member; eight to the grade of Associate Member; one to the grade of Junior, and one to the grade of Student Junior, and the receipt of eight applications for membership. One member was transferred to the grade of Member; two resignations were accepted, and one death reported.

No further business coming before the Society, the paper of the evening was presented by S. M. Kintner, Head Research Department, Westinghouse Electric & Manufacturing Company, and President International Devices Company, East Pittsburgh, Pa., on "By-Products of Radio Development."

A general discussion followed the presentation of the paper.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. Kintner for his very interesting paper.

The meeting adjourned at 9:45 P. M.

K. F. TRESCHOW, *Secretary.*

ALL-DAY CONFERENCE

An all-day conference of the Mining Section of the Engineers' Society of Western Pennsylvania was held jointly with the Pittsburgh Section of the American Institute of Mining and Metallurgical Engineers in the Blue Room, William Penn Hotel, Thursday, October 20, 1927, at 9:30 A. M., Chairman C. E. Lesher presiding, 215 members and visitors being present.

The minutes of the last meeting, held March 27, were dispensed with.

No further business coming before the meeting, the following papers were presented: "Mechanical Loading in the Pittsburgh District," by L. E. Young, Production Vice President, Pittsburgh Coal Company, Pittsburgh; "Conveyor System of the H. C. Frick Coke Company," by E. C. Auld, Assistant Chief Engineer, H. C. Frick Coke Company, Scottdale; and "Mine Locomotives Gathering and Main-Line Haul," by G. H. Shafter, Commercial Engineer, General Electric Company, Erie, Pa.

Written discussion was presented by Glenn B. Southward, American Mining Congress.

The ensuing discussion was participated in by: W. L. Affelder, Asst. to Pres., Hillman Coal & Coke Co.; B. H. Canon, Fort Pitt Coal & Coke Co.; J. M. Carmody, Editor, *Coal Age*, New York City; Mr. Chambers, Consolidation Coal & Coke Co., Fairmont, W. Va.; L. F. Crawford, Partner, Coal Mine Equipment Co.; J. A. Donaldson, Pres., Joy Machine Co., Franklin, Pa.; F. B. Dunbar, Gen. Supt. Mines, Hillman Coal & Coke Co.; F. M. Fritchman, Gen. Mgr., Rochester & Pittsburgh Coal & Iron Co., Indiana, Pa.; George E. Gramm, Elec. Engr., H. C. Frick Coke Co., Scottdale, Pa.; W. D. Hockensmith, Pres. & Gen. Mgr., Hockensmith Wheel & Mine Car Co., Penn, Pa.; Edwin H. Johnson, Mining Engr., Coloder Co., Columbus, O.; F. F. Jergenson, Consolidation Coal & Coke Co., Fairmont, W. Va.; A. B. Kiser, Gen. Supt., Electrical Equipment, Pittsburgh Coal Co.; C. E. Lesher, Executive V. P., Pittsburgh Coal Co.; B. H. McCracken, Maintenance Engr., Consolidation Coal Co., Inc., Fairmont, W. Va.; George F. Osler, V. P., Pittsburgh Terminal Coal Corp.; J. W. Paul, Mining Engr., U. S. Bureau of Mines; and the authors.

On motion, duly seconded and carried, a rising vote of thanks was extended to the authors of the papers for their interesting and instructive addresses.

The meeting adjourned at 4:20 P. M.

K. F. TRESCHOW, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Tuesday, October 18, at 4:10 P. M., Vice President John A. Hunter presiding in the absence of the President,. Messrs. Chester, Clifford, Stucki, Spellmire, Fohl, Covell and the Secretary being present, Messrs. Ladd, Affelder, Eavenson, Edgar, Fieldner, Forsberg, Lesher, Goodwin, McLoughlin and Johnston being absent.

The minutes of the last regular meeting, held September 20, were approved without reading.

Applications from the following gentlemen, having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Anderson, Harry Clifford
Beers, Harold S.
Dykeman, Howard E.
Dunbar, F. B.
Estep, Thomas G.
Ewalt, Dwight Sapp
Fisher, Charles A.
Holbrook, E. A.
Jones, Charles L.
Landahl, Eugene Everett
Mills, Charles Peale
Moore, R. W. E.
Peiffer, Thomas J.
Peth, Herbert William
Shotton, Bruce Gillespie
Tew, John Baker

ASSOCIATE MEMBERS

Danielson, George
Johnson, Fred McCoy
Lacock, J. S.
McKee, W. McC.
Over, Raymond W.
Richardson, Charles Parker
Schenck, Rand Gilmore
Waldschmidt, Howard Conrad

JUNIOR

Van Es, Joseph Henry

STUDENT JUNIOR

Martin, George Foster, Jr.

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Buell, Frank T.
Connor, Francis A.
Fisher, Gordon
Sandston, Leonard M.
Wagenseil, E. W.

ASSOCIATE MEMBER

Jeffries, Ernest

ASSOCIATE

Eissler, Robert Frederick

STUDENT JUNIOR

Eckels, Charles E., II

Application for transfer was received from Mr. Ten Eyck and, after discussion, the Secretary was requested to advise Mr. Ten Eyck of his transfer to the grade of Member.

Letters of resignation were received from the following and, after discussion, they were ordered accepted: G. N. Brown, G. B. Page.

The report of the Secretary, showing the condition of business at the close of business September 30, having been audited by the Finance Committee, was approved.

Mr. Covell, Chairman of the House Committee, reported an evening attendance of 290 for the month of September.

The Membership Committee held one meeting during the month to go over applications received since the last meeting and make assignment to the various grades of membership.

The Committee reported that letters had been sent to all the National Society members in Pittsburgh calling their attention to our facilities and inviting them to join under the special ruling of the Board.

Mr. Hunter, Chairman of the Finance Committee, reported that in accordance with the recommendation at the last meeting the Bond Department of the First National Band had secured a list of our bonds and, after going over them carefully, submitted recommendations for certain changes. These recommendations will be considered by the Committee appointed by the Board and action taken at a later date.

The Secretary reported the death of C. C. Hoover, who joined the Society in February, 1925, and died February 7, 1927.

No further business coming before the Board, the meeting adjourned at 5:20 P. M.

K. F. TRESCHOW, *Secretary.*

STEEL WORKS SECTION

The regular bi-monthly meeting of the Steel Works Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, William Penn Hotel, Tuesday, October 25, at 8:25 P. M., T. J. McLoughlin presiding, 67 members and visitors being present.

The minutes of the last meeting, held June 14, were read and approved.

There being no further business coming before the Section, the paper of the evening was presented by Victor Windett, Chief Inspection Engineer, Wellman-Seaver-Morgan Company, Cleveland, O., on "Observations on Gas-Producer Operation."

The ensuing discussion was participated in by: W. L. Affelder, Asst. to Pres., Hillman Coal & Coke Co.; W. B. Chapman, Pres., Chapman Engineering Co., New York City; E. A. Dobrin, Con. Engr., Birmingham, Ala.; W. N. Flanagan, Special Engr., Carnegie Steel Co.; P. Nicholls, Heat Transmission Engr., U. S. Bureau of Mines; L. J. Reed, Asst. Supt., Steam Dept., Aliquippa Works, Jones & Laughlin Steel Corp.; Clay Sprecher, Sales Engr., Pittsburgh, Pa.; Emil A. Vierow, Student, Carnegie Inst. of Technology; and the author.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. Windett for his very interesting and instructive paper.

The meeting adjourned at 9:48 P. M.

K. F. TRESCHOW, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Tuesday, November 15, at 4:10 P. M., President George T. Ladd presiding, Messrs. Chester, Hunter, Clifford, Affelder, Covell, Eavenson, Spellmire, Forsberg, and the Secretary being present, and Messrs. Stucki, Edgar, Fohl, Lesher, Goodwin, Fulton, Bayne, McLoughlin, Fieldner, and Johnston being absent.

The minutes of the last meeting, held October 18, were approved without reading.

Applications from the following gentlemen having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Buell, Frank T.
Fisher, Gordon
Connor, Francis A.
Sandston, Leonard M.
Wagenseil, E. W.

ASSOCIATE MEMBER

Jeffers, Ernest

ASSOCIATE

Eissler, Robert Frederick

STUDENT JUNIOR

Eckels, Charles E.

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Brown, James M.
Buenting, O. W.
Chandler, R. W.
Frazer, C. E.
Gare, Marshall Stearns
Harvey, C. K.
Huff, George F., Jr.
Jones, Frederick Woodbury
Lamb, Warren V.
Lee, Louis R.
Mayer, Raoul G.
McCune, Joseph C.
McGrew, A. B.
McIntyre, L. W.
Perrott, G. St. J.
Reese, Oliver P.
Smith, DuRay
Stroup, Earle Clifford
Walton, J. P.
Webster, W. R.
Wood, Frank J.
Worthington, Arthur Whittemore
Yeager, M. Edgar

ASSOCIATE MEMBERS

Crafton, H. Herbert
Fraunheim, Aloysius M.
Nelson, Ray Frederick
Smith, Albert
Ziegler, Nicholas A.

ASSOCIATES

Clement, A. E.
Munn, John F.
Staley, K. N.
Stotz, Norman I.
Weir, Paul Latimer

JUNIORS

Espenschade, P. W.
Grimes, L. W. David
Lyon, John A.

STUDENT JUNIOR

Evans, Norman H.

Application for reinstatement was received from D. G. Clark, and the Secretary was requested to advise him of his reinstatement to membership.

The Secretary reported the deaths of the following members:

J. M. Camp...........	Joined May, 1882	Died Oct. 24, 1927
C. J. Mogan...........	Joined Dec., 1904	Died Apr. 17, 1927
M. A. Neeland......	Joined May, 1894	Died Oct. 24, 1927
C. H. Nichols........	Joined Nov., 1891	Died Oct. 30, 1927

Special attention was called to our recent loss in the death of J. M. Camp, Past President of our Society, and, after discussion, it was regularly moved and carried that James O. Handy and J. N. Chester be appointed a committee of two to prepare a memoir of Mr. Camp.

The report of the Secretary showing the condition of business at the end of October 31, having been audited by the Finance Committee, was approved.

Mr. Clifford, Chairman of the Entertainment Committee, reported that arrangements were made for the Annual Banquet, but that no definite announcements could be made as to speakers at this time.

V. R. Covell, Chairman of the House Committee, reported an evening attendance of 320 for the month of October.

W. L. Affelder, Chairman of the Membership Committee, reported that one meeting of the committee had been held to go over applications received since the last meeting of the committee.

From letters of invitation to local members of the National Society we have received eight applications from the A. S. M. E., and four each from the A. I. E. E., A. S. C. E. and A. I M. & M. E.

Mr. Spellmire recommended that an engraved invitation be sent to C. S. McCalla, President of the Pennsylvania-Ohio Electric Light & Power Company, Youngstown, O., to join the Society. It was regularly moved and carried that the Secretary be instructed to extend the invitation.

In accordance with Article 5, Section 5, of the By-Laws, the Board of Direction is required to approve at the November meeting the eligibility of nominees for the various offices to be filled in the November election report of the Nominating Committee, as follows:

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

DEAR SIRS—Your Nominating Committee appointed to nominate officers for the Society for the ensuing year met today and wish to report as follows:

President....................	John A. Hunter
Vice President....................	W. L. Affelder
Treasurer	A. Stucki
Directors....................	T. J. McLoughlin A. S. Davison

Respectfully submitted,

W. E. FOHL, *Chairman,*
W. B. SKINKLE,
J. F. LABOON,
J. MILLIKEN,
C. S. DAVIS,
Nominating Committee.

It was regularly moved and carried that the report be approved and the Secretary instructed to publish these names on our next announcement in accordance with the By-Laws.

The Secretary preesnted a letter from the Western Society of Engineers of Chicago suggesting that in accordance with the recent amendment in our By-Laws permitting us to exchange memberships with other local engineering organizations granting similar privileges to our Society, an exchange be effected as of November 15. It was regularly moved and carried that the Secretary write the Western Society that such an exchange has been approved by the Board of Direction.

The meeting adjourned at 5:10 P. M.

K. F. TRESCHOW, *Secretary*.

ELECTRICAL SECTION

The regular monthly meeting of the Electrical Section of the Engineers' Society of Western Pennsylvania was held jointly with the Pittsburgh Section of the American Institute of Electrical Engineers in the Chamber of Commerce Auditorium, Wednesday, November 9, at 7:40 P. M., Secretary H. E. Dyche presiding, 325 members and visitors being present.

Motion pictures were shown, after which the paper of the evening, on "The Modern Oscillograph—the Analyst of the Unknown," was presented by Joseph W. Legg, Supply Engineering Department, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

Result of movie ballot held at the last meeting was as follows:

Preferred 6:30 P. M. for movies	42
Preferred 7:00 P. M. for movies	60
Preferred fight movies	2
Preferred no movies	2
Preferred talking movies	1

A vote of thanks was extended to Mr. Legg for his very interesting paper.

The meeting adjourned at 10:10 P. M.

K. F. TRESCHOW, *Secretary*.

REGULAR MONTHLY MEETING

The four hundred and fiftieth regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, November 15, at 8:20 P. M., President George T. Ladd presiding, 120 members and visitors being present.

The minutes of the last meeting, held October 18, were read and approved.

The Board of Direction reported the election of five applicants to the grade of Member; one to the grade of Associate Member; one to the grade of Associate, and one to the grade of Student Junior. One reinstatement was reported and four deaths, and receipt of 37 applications for membership.

No further business coming before the Society, the paper of the evening was presented by H. C. Whitehurst, Captain, Corps of Engineers, U. S. Army, on the "Construction of the Muscle Shoals Dam."

A general discussion followed the presentation of the paper.

On motion, duly seconded and carried, a vote of thanks was extended to Captain Whitehurst for his very interesting talk.

The meeting adjourned at 10:15 P. M.

K. F. TRESCHOW, *Secretary*.

ILLUMINATING ENGINEERS' SECTION

The regular monthly meeting of the Illuminating Engineers' Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, November 22, at 8:15 P. M., Chairman H. L. Johnston presiding, 85 members and visitors being present.

The reading of the minutes of the last meeting was dispensed with.

There being no further business coming before the Section, the paper of the evening, on "Night Flying," was presented by L. C. Porter, Engineer in Charge Aviation Lighting, General Electric Company, Schenectady, N. Y.

A general discussion followed the presentation of the paper.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. Porter for his very interesting paper.

The meeting adjourned at 10:08 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Tuesday, December 13, at 4:10 P. M., President George T. Ladd presiding, Messrs. Hunter, Chester, Clifford, Edgar, Spellmire, Fohl, Covell and Johnson being present, and Messrs. Stucki, Affelder, Eavenson, Fieldner, Forsberg, Lesher, Goodwin, Fulton, Bayne and McLoughlin being absent.

The minutes of the last meeting, held November 15, were approved without reading.

Applications for membership from the following gentlemen having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Brown, James M.
Buenting, O. W.
Chandler, R. W.
Frazer, C. E.
Gare, Marshall Stearns
Harvey, C. K.
Huff, George F., Jr.
Jones, Frederick Woodbury
Lamb, Warren V.
Lee, Louis R.
McCune, Joseph C.
McGrew, A. B.
McIntyre, L. W.
Mayer, Raoul G.
Perrott, G. St. J.
Reese, Oliver P.
Smith, DuRay
Stroup, Earle Clifford
Walton, J. P.
Webster, W. R.
Wood, Frank Joseph
Worthington, Arthur Whittemore
Yeager, M. Edgar

ASSOCIATE MEMBERS

Crafton, H. Herbert
Frauenheim, Aloysius M.
Nelson, Ray Frederick
Smith, Albert
Ziegler, Nicholas A.

ASSOCIATES

Clement, A. E.
Munn, John F.
Staley N. A.
Stotz, Norman I.
Weir, Paul Latimer

JUNIORS

Grimes, L. W. David
Espenschade, P. W.
Lyon, John A.

STUDENT JUNIOR

Evans, Norman H.

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Chesterman, F. J.
Frank, Robert J.
Purcell, Thomas Edward
Wessel, A. H.
Mohlgemuth, M. J.
Staege, Stephen A.

ASSOCIATE MEMBER

Steuber, M. C.

ASSOCIATE

Cook, R. J.

JUNIOR

Griggs, Thomas Newell

The report of the Secretary showing the condition of business at the end of November 30, having been audited by the Finance Committee, was approved.

In connection with the Secretary's report, Mr. Hunter reported that in accordance with instructions received at the September meeting of the Board, negotiations have been completed with the First National Bank for the transfer of certain bonds of the Society as follows:

Sold:

2 Penna. Railroad Cons. Mtg. Issue of 1915 Bonds, Nos. 27320-1, Aug. 1, 1960, 4½ per cent., Aug. 1, 1926	$2000.00
2 Baltimore & Ohio R. R. Ref. & Gen. Mtg. Bonds "D," Nos. 28671-2, Mar. 1, 2000, 5 per cent., Sept. 1, 1926	2000.00
2 Union Steel Casting Co. 1st Mtg. & Col. Tr. 50 Yr. Gold Bonds, Nos. 36642-3, Dec. 1, 1952, 5 per cent., Dec. 1, 1926	2000.00
1 Butler Water Co. Gold Bond, No. 9, Sept. 2, 1931, 5 per cent., Sept. 1, 1926	1000.00

Bought in exchange:

2 Shell Pipe Line 25 Yr. 5 Per Cent. S. F. Gold Bonds, due Nov. 1, 1952, at $98.00 net and accrued interest.

3 Follansbee Bros. Co. First Mtg. 5 Per. Cent. S. F. Gold Bonds, due June 1, 1947, at 98½ net and accrued interest.

2 Wheeling Steel Corp. First & Ref. Mtg. 5½ Per Cent. S. F. Gold Bonds, due July 1, 1948, at 101½ net and accrued interest.

It was regularly moved and carried that the action of the Chairman of the Finance Committee be approved in the transfer of these bonds.

The question of investing the interest from our bonds was discussed, but no definite action was taken. It was suggested during this discussion that Board members felt this interest should be reinvested rather than placed in the General Fund for current expenses.

The matter of our yearly audit was also discussed, and the Secretary authorized to secure the usual audit.

In view of the possibility of the necessity of an increase in dues, it was suggested by Mr. Fohl that additional copies of this audit be secured and one sent to each member of the Board in order that a careful study of our expenditures and receipts may be made. It was moved and carried that the Secretary have sufficient number of these copies made for each member.

The Secretary reported that, in accordance with the discussion at the last meeting, Mr. Porter had called on practically all of the delinquent members on the list presented at the last meeting, residing in Pittsburgh, and had secured the promise from some to pay before the end of the year and others to pay up soon after the first of the year. All of them expressed a desire to continue their membership.

Mr. Clifford, Chairman of the Entertainment Committee, reported that no definite arrangements had been completed as yet for the Annual Banquet, but that the committee expected to have the list of speakers complete by the first of the year.

Mr. Covell, Chairman of the House Committee, reported an evening attendance of 374 for the month of November.

One meeting of the Membership Committee was held during the month to go over applications and assign them to the various grades of membership.

In accordance with Article 5, Section 5, of the By-Laws, the Board of

Direction finally approved the names of the nominees as presented by the Nominating Committee at the November meeting of the Board as follows:

For President ....John A. Hunter
For Vice President ....W. L. Affelder
For Treasurer .... A. Stucki
For Directors.. { A. S. Davison / T. J. McLoughlin

The meeting adjourned at 5:10 P. M.

K. F. TRESCHOW, *Secretary.*

STEEL WORKS SECTION

The regular bi-monthly meeting of the Steel Works Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Thursday, December 1, Chairman T. J. McLoughlin presiding, 120 members and visitors being present.

The minutes of the last meeting, held June 14, were read and approved.

No further business coming before the Section, the paper of the evening, on "Continuous Annealing Furnaces," was presented by F. W. Manker, Vice President, Surface Combustion Company, New York, N. Y.

The ensuing discussion was participated in by: H. C. Anderson, Chf. Engr, American Sheet Opener Co. and Blasko Corp, Apollo, Pa.; W. M. Austin, Engr, Westinghouse Elec. & Mfg. Co.; W. F. Canther, Duraloy Co.; L. W. Haag, Chf. Engr, Apollo Steel Co.; E. B. Plapp, Sales Engr, Combustion Engineering Corp.; Barton R. Shover, Con. Engr, Pittsburgh; and the author.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. Manker for his very interesting and instructive paper.

The meeting adjourned at 10:07 P. M.

K. F. TRESCHOW, *Secretary.*

REGULAR MONTHLY MEETING

Joint Meeting of the General Society, Engineers' Society of Western Pennsylvania, and the Pittsburgh Section, American Institute of Electrical Engineers

The four hundred and fifty-first regular monthly meeting of the Engineers' Society of Western Pennsylvania was held jointly with the Pittsburgh Section of the American Institute of Electrical Engineers on Tuesday, December 13, in the Chamber of Commerce Building Auditorium, at 8:00 P. M., Secretary H. E. Dyche presiding, 275 members and visitors being present.

The minutes of the last meeting, held November 15, were approved without reading.

The Board of Direction reported the election of 23 applicants to the grade of Member, five to the grade of Associate Member, five to the grade of Associate, three to the grade of Junior, and one to the grade of Student Junior, and the receipt of nine applications for membership.

A motion picture was shown, after which the paper of the evening, on "The Engineer vs. the Salesman—Who's Ahead?" was presented by G. M. Gadsby, President, West Penn Power Company, Pittsburgh, Pa. A general discussion followed the presentation of the paper.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. Gadsby for his very interesting paper.

The meeting adjourned at 9:45 P. M.

K. F. TRESCHOW, *Secretary.*